

MATERIAL SPECIFIC HEMISPHERIC ACTIVATION

By

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TO DIANE

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## MATERIAL SPECIFIC HEMISPHERIC ACTIVATION

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It has been previously demonstrated that binaurally presented verbal warning stimuli (WS) asymmetrically reduce reaction times (RT) of the right hand to a midline neutral stimulus. However, nonverbal auditory WS reduce RTs of both hands equally. These findings have been interpreted as providing partial support for the hypothesis that verbal and nonverbal materials differentially activate and prepare the hemispheres for action.

The purpose of the present study was: (a) to determine whether verbal and nonverbal WS in the visual modality differentially reduce RTs of the hands; (b) to determine the extent to which this asymmetric RT reduction is temporally related to the WS; and (c) to determine whether a response-linked decisional process is necessary for inducing these asymmetries.

Thirty-two dextral college students performed a RT task in which manual RTs were obtained to a binaurally presented tone (500 ms) that was

preceded at random intervals (500-1500 ms) by either a word or face WS. The WS were tachistoscopically presented at central fixation for 250 ms. During any one session, only one type of WS (verbal or nonverbal) was presented, and right and left hand responses were measured.

If verbal and nonverbal materials differentially activate and prepare the hemispheres for action, then verbal WS should selectively reduce right hand RTs and nonverbal WS should reduce left hand RTs. To determine whether the asymmetric RT reduction, induced by the verbally or nonverbally warned trials, persists on the order of 15-20 sec, 48 unwarned trials in which no WS preceded the RT stimulus were presented. These unwarned trials were randomly embedded among the 192 warned trials of each session. Thus, if asymmetric activation is persistent during the session, the RT asymmetries should also be obtained for these unwarned embedded trials.

Prior to and following each verbal and nonverbal session, simple unwarned RTs were also obtained for each hand. This was done to determine whether asymmetric hemispheric activation might extend beyond the verbal/nonverbal session itself and affect post-session trials by inducing RT asymmetries.

Sixteen subjects (Ss) were assigned to a "go-no go" RT task in which half the WS during any one session signalled that a response should be made to tone onset and the remaining WS signalled that no response should be made. Four sessions of 192 trials each were administered in the "go-no go" task. In two sessions, words were used as WS and in two sessions, faces were used. The other 16 Ss were assigned to a simple RT task in which responses were made on every trial. Two sessions (one verbal and one nonverbal) of 192 trials each were administered in the simple RT task. If the predicted RT

asymmetries are found only in the "go-no go" task, in which a decision to respond is based on the information conveyed by the WS, this would suggest that the decisional process is important for inducing asymmetric hemispheric activation (i.e., preparation for action or readiness to respond). If the predicted RT asymmetries are also found in the simple RT task, this would suggest that asymmetric activation is not decisionally dependent.

The results showed that: (a) In the "go-no go" task, verbal WS asymmetrically reduced RTs of the right hand more than left hand RTs. However, nonverbal WS reduced RTs of both hands equally; (b) For the embedded unwarned trials, there was only a trend for faster RTs by the right hand when verbal WS were used, suggesting that asymmetric activation is temporally related to the WS. For the post-session unwarned trials, the predicted between-hand asymmetries were not found. The RTs following the verbal sessions were slower than those following the nonverbal sessions, suggesting that verbal/nonverbal WS induced differential fatigue effects; and (c) In contrast to the "go-no go" task, no RT asymmetries were found in the simple RT task, suggesting that asymmetric hemispheric activation is linked to a decisional process.

These findings are discussed in terms of the implications for attentional versus structural models of perceptual asymmetries on laterality tasks. The role of right hemisphere attentional mechanisms is also addressed.

## INTRODUCTION

### Overview of the Problem

An extensive body of data collected over the past century has been generally interpreted as supporting the notion that the two cerebral hemispheres of man's brain are differentially involved in linguistic and cognitive functions (Gazzaniga, 1970; Geschwind, 1970). Based on current ways of interpreting structure-function relationships, it appears that the left hemisphere processes most, if not all, linguistic stimuli and the right hemisphere processes many, if not most, visuospatial stimuli.

This hypothesis concerning cerebral laterality function was initially drawn from clinical studies of patients following unilateral neurologic insult to the left or the right hemisphere. The development of various lateral perceptual stimulation techniques approximately 20 years ago enabled researchers to address for the first time cerebral laterality of function in normal intact individuals, thereby circumventing some of the difficulties inherent in the classical "lesion" approach to this problem. Research using these laterality tasks with normal adults has demonstrated that language stimuli are more readily perceived when presented contralateral to the left hemisphere and that nonlanguage stimuli are better perceived when presented contralateral to the right hemisphere.

While it has been widely accepted that the perceptual asymmetries obtained on such laterality tasks reflect the divergent functions of the two hemispheres, the precise neurophysiological mechanisms underlying such asymmetries has been controversial. At least two such mechanisms

have been proposed to explain perceptual asymmetries. One is based on a structural anatomical model (Kimura, 1961, 1967) and the other is based on a more functional attentional-activational model (Kinsbourne, 1970a, 1975).

The present study represents an attempt to experimentally differentiate between these two models of perceptual asymmetries and specifically addresses the hypothesis that verbal and nonverbal materials asymmetrically activate and prepare the hemispheres for action. Since the evaluation of this "material specific hemispheric activation" hypothesis bridges two main content areas, that dealing with cerebral laterality of function and that dealing with attention and its underlying neurophysiological mechanisms, each of these topics will be addressed in the following sections.

### Laterality of Cerebral Function

#### Historical Perspectives

The view that the dual function of the human brain relies on a functional verbal-nonverbal dichotomy is historically rooted in the early localizationist school of classical neurology. During the early half of this century, ideas regarding cortical functioning were dominated by two "streams of thought," that initiated by Broca (1861) and Wernicke (1874) which emphasized localization, and that including Head (1926), Goldstein (1927, 1948), and Lashley (1929) which was anti-localizationistic (Geschwind, 1963, 1967).

The rapid historical movement towards the idea that different cognitive functions are localized in different parts of the brain was prompted by Gall in the early 1800's with his theory of phrenology (Blake-more, 1977). It was not until Broca's (1861) discovery, that anterior

lesions of the left hemisphere produced expressive language disturbances, that the localizationist school gained its first scientific respectability. Subsequently, Wernicke (1874) identified another form of aphasia that was produced by more posterior lesions in the left hemisphere. Not only did Wernicke provide new evidence for the localization of aphasia, he also advanced a theory which tied these phenomena to existing knowledge of anatomical fiber tracts in the brain (Geschwind, 1963, 1967). On the basis of Wernicke's theory, it was possible to predict the existence of clinical syndromes not previously seen. It was the theoretical aspect of Wernicke's approach that gave rise to the "golden age of neurology," during which a myriad of neurological syndromes were identified over the next 40 years and related to lesions of particular cortical areas.

The anti-localizationists, on the other hand, argued that one could not pinpoint one-to-one relationships between language and cortical functions. One of the foremost proponents of this view was Goldstein (1927, 1948), whose psychological approach to the study of brain injuries coincided with the academic gestalt movement in this country and Germany. Goldstein stressed the "equipotentiality" of the brain and argued that differences in clinical syndromes might reflect the extent of brain damage rather than the precise site of the lesion. In particular, he emphasized that abstract categorical behavior, i.e., the "abstract attitude," was more dependent on the actual mass of brain tissue involved than on the participation of discrete cortical areas.

According to Geschwind (1964), the seemingly contradictory perspectives of the localizationists and the holists are somewhat artificial and misleading, in that the similarities between these two points of

view far outweigh their differences. The holists, for example, supported the main anatomical tenets of the localization school, and like the latter, even postulated the existence of "conceptual centers" which corresponded to the "centers" and "schemas" to which they objected (Geschwind, 1964). What remains indisputable is that both views acknowledged that verbal functions were more easily disrupted by lesions of the left than the right hemisphere. This observation consequently led to the hypothesis that language was lateralized to the left hemisphere and that non-language functions were lateralized to the right hemisphere (Jackson, 1874).

Until approximately 20 years ago, research in cerebral asymmetry of function was limited to the study of individuals following neurologic insult. This clinical approach to the neural localizations of function is based on the association of cognitive deficits with known cortical lesions and is subject to logical limitations. In studies of patients with discrete cortical lesions, one is never assessing directly the function of the lesioned area, but rather inferring its function from the manner in which the remainder of the intact brain has compensated for its loss.

This inferential problem is further compounded when models of "normal" brain functioning are then based on findings from neurologically deviant populations, i.e., split-brain patients whose neocortical commissures have been surgically sectioned as a "last resort" attempt to control seizures. A voluminous amount of research over the past decade using such "split-brain" patients has given rise to models which attempt to explain the divergent functions of the left and right hemispheres (Nebes, 1974). The problem which emerges is that the majority of these

individuals have had long-standing seizure disorders, which greatly magnify the probability of major cortical reorganization. Data directly bearing on this caveat has been recently provided by Whitaker (1978) from a series of cortical mapping studies carried out on epileptics prior to the removal of seizure foci. In Whitaker's series, the vast majority of these epileptics had grossly deviant topographical arrangements of motor, sensory, and language areas within the left hemisphere. Such findings suggest that one should proceed cautiously when generating models of brain function based on pathological populations.

The development of various lateral sensory stimulation tasks, i.e., dichotic listening, visual half field procedures, dichotomous stimulation, has enabled researchers to assess cerebral laterality of function in normals. Use of these laterality tasks has involved the presentation of sensory stimuli (i.e., visual, auditory, tactile) to one or both lateral sides of the body (i.e., ear, visual half field, hand), to which a subject is required to make some discriminative judgement about its occurrence (i.e., recall, recognition, reaction time). In dichotic listening (DL), initially developed by Broadbent (1958) for the study of attention and later adopted by Kimura (1961), competing auditory stimuli are simultaneously presented to each ear via stereo headphones. Similarly, visual half field (VHF) tasks involve the tachistoscopic presentation of visual stimuli to either or both left and right VHFs. Finally, dichotomous tactile stimulation procedures, recently developed by Witelson (1974), entail the manual palpation of different three-dimensional forms by the left and right hands.

Most investigators have accepted Kimura's (1961, 1967) initial claim that the perceptual asymmetries obtained on such tasks reflect

the underlying asymmetric functions of the two hemispheres for processing verbal and nonverbal materials. There is, in fact, so much evidence in favor of this hypothesis that it would be difficult to refute. It has been repeatedly found that language stimuli are better detected when presented to the right than left channel (ear, VHF, hand), whereas nonlanguage stimuli are better detected when presented to the left channel. The right-sided advantage for language stimuli and the left-sided advantage for nonlanguage stimuli have been thought by some investigators to reflect the most direct access of stimuli, via contralateral sensory pathways, to the hemisphere most specialized for processing them (Kimura, 1961, 1967; Moscovitch, 1973). Other investigators have attributed these perceptual asymmetries to attentional mechanisms (Kinsbourne, 1970a, 1975).

Over the past decade, the focus of laterality research has taken several different directions. At one end of the spectrum are a myriad of analytic studies which have attempted to identify various aspects of stimulus parameters which give rise to perceptual asymmetries. Some of these parameters have included, among others, various acoustic, phonetic, semantic, syntactic, and configurational aspects of stimuli. A synopsis of the major findings of some of these studies using right-handed adults as subjects (Ss) is provided in Tables 1-5. At the other end of the spectrum are studies concerned with individual differences in perceptual asymmetries and with their relationships to other behaviors, i.e., learning disabilities (Satz, 1975), sex (McGlone & Davidson, 1973; Waber, 1976; Witelson, 1976), handedness (Fennell, Satz, Van Den Abell, Bowers, & Thomas, 1978; Levy, 1974), and personality characteristics (Zoccolatti & Ottman, 1978).

TABLE 1

SYNOPSIS OF DICHOTIC LISTENING STUDIES WITH RIGHT-HANDED ADULTS  
ACCORDING TO THE TYPES OF STIMULI THAT PRODUCE RIGHT EAR (RE), LEFT EAR (LE), OR NO BETWEEN-  
EAR DIFFERENCES FOR THE RECALL-RECOGNITION OF DICHOTIC STIMULI

Right Ear Advantages

Stimuli	Investigator(s)
Meaningful words	Curry (1967)
Nonsense words	Curry (1967)
Words	Dee (1971)
Words	Dirks (1964)
Rhyming words	Yeni-Komshian & Gordon (1974)
Familiar abstract nouns	Hines (1976)
Unfamiliar abstract nouns	Hines (1976)
Familiar concrete nouns	Hines (1976)
Unfamiliar concrete nouns	Hines (1976)
Concrete words	Fennell, Bowers, & Satz (1977)
Digits	Kimura (1961)
Digits	Gordon (1976)
Digits	Hines & Satz (1974)
Digits	Knox & Kimura (1964)
Digits	Satz, Achenback, Pattishall, & Fennell (1965)
Synthetic stop consonants	Shankweiler & Studdert-Kennedy (1967)
Syllables differing in initial stop consonants	Haggard (1971)
Consonant-vowel-consonants (CVC) with initial consonant contrasts	Studdert-Kennedy & Shankweiler (1970)
CVCs with final consonant contrasts	Studdert-Kennedy & Shankweiler (1970)
Consonant-vowels (CVs)	Yund & Efron (1976)
Voiced and unvoiced CVs	Repp (1978)
Consonant-liquid-vowels (i.e., gli)	Cutting (1972)
Vowels with white noise masking	Godfrey (1974)

TABLE 1 (cont.)

Stimuli	Investigator(s)
Backward speech	Kimura & Folb (1968)
Prosodic and nonprosodic nonsense word sentences	Zurif & Sait (1970)
Structured syntactic sequences	Heeschen & Jurgens (1977)
Syllables differing in tone for Thai subjects	Van Lancker & Fromkin (1973)
Melodies differing in rhythm	Gordon (1978)
<u>Left Ear Advantages</u>	
Intonation contours	Blumstein & Cooper (197 )
Pitch contours (2nd report)	Oscar-Berman, Goodglass, & Donnefeld (1974)
Pitch	Efron & Yund (1974)
Environmental sounds	Curry (1967)
Environmental sounds	Knox & Kimura (1964)
Musical chords	Gordon (1970)
Musical chords	Gordon (1978)
Melodies	Kimura (1964)
Four-note melodies	Dee (1971)
Violin melodies in nonmusicians	Johnson (1977)
CVs when between-ear intensity and signal:noise ratio is varied	Cullen, Thompson, Hughes, & Berlin (1974)
<u>No Ear Differences</u>	
Vowels	
Vowel contrasts (i.e., bip versus bap)	Shankweiler & Studdert-Kennedy (1967)
Structured semantic-pragmatic sequences	Studdert-Kennedy & Shankweiler (1970)
	Heeschen & Jurgens (1977)

TABLE 1 (cont.)

Stimuli	Investigator(s)
Two-note tonal sequences	Efron & Yund (1974)
Nonverbal rhythmic sequences	Natale (1977)
Tones in nonlinguistic contexts	Van Lanker & Fromkin (1973)
Dichotic chords	Yund & Efron (1976)
Melodies differing in pitch, but similar in rhythm	Gordon (1978)
Harmony changes	Gates & Bradshaw (1977)

TABLE 2

SYNOPSIS OF DICHOTIC LISTENING STUDIES WITH RIGHT-HANDED ADULTS  
ACCORDING TO THE TYPES OF STIMULI THAT PRODUCE RIGHT EAR (RE), LEFT EAR (LE), OR NO BETWEEN-  
EAR DIFFERENCES (ND) IN REACTION TIME TO DICHOTIC STIMULI

Stimuli	Investigator(s)
Consonant vowels (CVs)	Springer (1971)
CVs	Hughes (1978)
Words	Levy & Bowers (1974)
Sentences	Shanon (1974)

\*No reported studies found left ear or no-ear differences.

TABLE 3

SYNOPSIS OF VISUAL HALF FIELD (VHF) STUDIES WITH RIGHT-HANDED ADULTS  
 ACCORDING TO THE TYPES OF STIMULI THAT PRODUCE RIGHT VHF, LEFT VHF, OR NO VHF DIFFERENCES (ND)  
 FOR THE RECALL-RECOGNITION OF VISUAL STIMULI

Stimuli	Investigator(s)
	<u>Right VHF Advantages</u>
Digits	Hines, Satz, Schell, & Schmidlin (1969)
Digits	Hines, Satz, & Clementino (1973)
Digits	Hines & Satz (1974)
Letters	Rosen, Curcio, Mackavey, & Hebert (1975)
Letters	Bryden (1973)
Words	Hines (1975)
Words with fixation control	Hines (1972)
Words	Andrews (1977)
High frequency words	Leiber (1976)
High frequency words	Bradshaw & Gates (1978)
Low frequency words	Leiber (1976)
Low frequency words	Bradshaw & Gates (1978)
Unambiguous nouns (i.e., river)	Caplan, Holmes, & Marshall (1974)
Agentive nouns (i.e., giver)	Caplan et al. (1974)
Ambiguous nouns (i.e., father)	Caplan et al. (1974)
Nonsense words	Hannay & Malone (1976)
Nonsense words	Bradshaw & Gates (1978)
Trigrams	Hilliard (1973)
Vowel trigrams	Andrews (1977)
Consonant trigrams	Andrews (1977)
Words in print-like typescript	Bryden & Allard (1976)
Shapes without fixation control	Hines (1972)
Shapes	Hines (1975)
Famous faces	Marzi & Berlucchi (1977)

TABLE 3 (cont.)

Stimuli	Investigator(s)
<u>Left VHF Advantages</u>	
Faces	Hilliard (1973)
Faces	Gilbert (1973)
Faces	Ellis & Shepherd (1975)
Inverted faces	Ellis & Shepherd (1975)
Orientation of lines	Fontenot & Benton (1972)
Icons of music symbols with manual response	Oscar-Berman, Blumstein, & DeLuca (1976)
Van Der Plas figures	Dee & Fontenot (1973)
Dot detection	Davidoff (1977)
Words in script-like typeface	Bryden & Allard (1976)
Orientation of lines	Sasanuma & Kobayashi (1978)
<u>No VHF Differences</u>	
Number of dots	Adams (1971)
Orientation of dot patterns	Adams (1971)
Dot localization	Bryden (1973)
Forms	Bryden (1973)
Forms with fixation control	Hines (1972)
Icons of music symbols with verbal report	Oscar-Berman et al. (1976)
Faces	Hines (1975)
Words without fixation control	Hines (1972)
Pronounceable and unpronounceable nonwords	Leiber (1976)
Consonant-vowel syllables	Hannay & Malone (1976)
Categorical judgements of English and Chinese words by bilinguals	Hardyck, Tzeng, & Wang (1976)

TABLE 4

SYNOPSIS OF VISUAL HALF FIELD STUDIES (VHF) WITH RIGHT-HANDED ADULTS  
ACCORDING TO THE TYPES OF STIMULI THAT PRODUCE RIGHT VHF, LEFT VHF, OR NO VHF DIFFERENCES (ND)  
IN REACTION TIME TO VISUAL STIMULI

Stimuli	Investigator(s)
Letters	Geffen, Bradshaw, & Wallace (1971)
Letters	Rizzolatti, Umilta, & Berlucchi (1971)
Letters	Umilta, Frost, & Hymen (1972)
Letters	Moscovitch (1973)
Words	Klein, Moscovitch, & Vigna (1976)
English and Chinese words	Hardyck, Tzeng, & Wang (1978)
Name identity matches of letters (i.e., Aa)	Davis & Schmit (1973)
Horizontal and vertical angles	Umilta, Rizzolatti, Marzi, Zamboni, Franzini, Camarda, & Berlucchi (1974)
Faces	Patterson & Bradshaw (1975)
Faces	Gilbert (1977)
Faces	Rizzolatti et al. (1971)
Faces	Geffen et al. (1971)
Faces	Klein et al. (1971)
Faces	Moscovitch, Scullion, & Christie (1976)
Faces	Patterson & Bradshaw (1975)
Faces	Suberi & McKeever (1977)
Emotional and nonemotional faces	Davis & Schmit (1973)
Physical identity matches of letters (i.e., AA)	Bertoloni, Anzola, Buchtel, & Rizzolatti (1978)
Velocity of movement	Umilta et al. (1974)
Oblique angles	Longden, Ellis, & Iverson (1976)
Line curvature	

TABLE 4 (cont.)

Stimuli	Investigator(s)
Letters	Gilbert (1974) Bertoloni et al. (1978) Moscovitch et al. (1976)
Dot duration	
Faces	

TABLE 5

SYNOPSIS OF DICHOTOMOUS STUDIES WITH RIGHT-HANDED ADULTS ACCORDING TO  
THE TYPES OF STIMULI THAT PRODUCE RIGHT HAND (RH), LEFT HAND (LH), OR NO BETWEEN-HAND  
DIFFERENCES FOR THE RECOGNITION OF TACTILE STIMULI

Stimuli	Investigator(s)
Nonsense shapes	Witelson (1974) Gardner, English, Flannery, Hartnett, McCormick, & Wilhelmong (1977)
Nonsense shapes	
<u>Left Hand Better*</u>	
<u>No Between-Hand Differences</u>	
Letters	Witelson (1974)

\*No reported studies found the right hand to be better with tactile stimuli.

### Current Models of Cerebral Laterality of Function

Two laterality models have been proposed which attempt to describe the functional specialization of the two cerebral hemispheres. According to one, each hemisphere is specifically organized to mediate different types of stimuli. This "stimulus-specific" model maintains that verbal stimuli are processed by the left hemisphere and that nonverbal stimuli are processed by the right hemisphere (Kimura, 1967). The second model postulates that both hemispheres can mediate all types of stimuli, although each employs qualitatively different processing strategies (Goldberg, Vaugh, & Gerstman, 1978). This "strategy-specific" model maintains that each hemisphere has its own characteristic processing systems for analyzing component parts of a stimulus.

According to the "stimulus-specific" model, there is a pronounced separation of linguistic and nonlinguistic skills into the left and right hemispheres, respectively (Kimura, 1967). Underlying this model is the implicit assumption that the two halves of the brain are similar in the degree of their neural specialization. Namely, different functions are localizable to the same extent within each hemisphere. According to this assumption, one would expect laterality effects to be equally consistent in terms of reliability and magnitude for the left and the right hemispheres. Effects of this sort, however, have not been obtained. Laterality effects for nonverbal materials with neurologically intact adults using either DL or VHF procedures are generally smaller than effects with verbal materials and less consistently obtained (White, 1973). In addition, the effects of brain damage to the right hemisphere are much less clearcut than effects of damage to the left hemisphere (DeRenzi & Faglioni, 1965).

Furthermore, the "stimulus-specific" model has produced few detailed explanations of the mechanisms underlying such specialization. Semmes (1968), for example, has stated that:

Unfortunately, the concept of cerebral dominance is not helpful for it proposes nothing about mechanism; in fact, it is little more than a label, a restatement of findings that lesions of one hemisphere produce deficits that lesions of the other hemisphere do not. (p. 11)

Just as the label "cerebral dominance" fails to explain, so the labels "linguistic skill" and "visuospatial skill" offer little help in understanding the formal nature of the abilities referred to (Marshall, 1973). Vygotsky (1965) claimed that classical investigations ". . . failed to arrive at an adequate solution of the problem because of the lack of structural-psychological analysis of the functions they try to localize" (p. 381). He further argued that ". . . the problem of what can be localized is not at all irrelevant to the problem of 'how' it can be localized in the brain" (p. 382).

Several hypotheses have been proposed which attempt to explain hemispheric specialization in the spirit of Vygotsky's remarks. Recent candidates for the mode of operation of the left and right hemispheres, respectively, include: Analytic versus Gestalt processing (Levy & Sperry, 1968); Serial versus Parallel processing (Cohen, 1972); Categorical versus Noncategorical judgements (Goldberg, Vaughn, & Gerstman, 1978); Similarity versus Dissimilarity judgements (Egeth & Epstein, 1972); Name versus Physical Identity judgements (Cohen, 1973; Klatzky, 1972); and Categorical versus Place judgements (Veroff, 1978). Historically, these modes of information processing, which have been attributed to the two hemispheres, have been labelled in many different ways, some of which are

TABLE 6

## DICHOTOMIES OF LATERALIZATION

Goldberg, Vaughn, & Gerstman (1978)	Categorical-Noncategorical
Veroff (1978)	Categorical-Placement
Cohen (1973)	Serial-Parallel
Egeth & Epstein (1972)	Similarity-Dissimilarity
Klatzky (1972); Cohen (1972)	Name-Physical Identity
Bogen (1969)	Propositional-Appositional
Bogen & Gazzaniga (1969)*	Verbal-Visuospatial
Hall & Hall (1968)	Analytic-Gestalt
Levy & Sperry (1968)	Analytic-Gestalt
Hecaen, Ajuriaguerra, & Angelergues (1963)*	Linguistic-Preverbal
Zangwill (1961)*	Symbolic-Visuospatial
Semmes, Weinstein, Ghent, & Teuber (1961)*	Discrete-Diffuse
Milner (1958)*	Verbal-Perceptual
McFie & Piercy (1952)*	Education or relations- Education of correlates
Humphrey & Zangwill (1951)*	Symbolic-Visual Propositional-Imaginative
Anderson (1951)*	Storage-Execution
Weisenberg & McBride (1935)*	Linguistic-Visual
Jackson (1876)*	Propositional-Visual imagery
Jackson (1874)*	Audio articulator-Visual imagery
Jackson (1864)*	Expressive-Receptive

\*Taken from Bogen (1969)

found in Table 6. Whether these presumed modes represent identical, related, or independent hypotheses regarding a formal mechanism is not known.

Thus, a "strategy-specific" model of cerebral laterality of function maintains that each hemisphere has its own "descriptive systems" for processing and encoding stimuli (Goldberg, Vaughn, & Gerstman, 1978). These putative "descriptive systems" do not necessarily coincide with the simple language-nonlanguage dichotomy which the "stimulus-specific" model of laterality maintains. Rather, the emphasis of the "strategy" approach involves a delineation of the processing characteristics of the two hemispheres, regardless of the verbal-nonverbal or modality classifications of stimuli. From this perspective, laterality effects would depend on the degree of relevance that classes of stimuli have to existing "descriptive systems," thus forming gradients of relative left-right hemispheric involvement in processing these materials.

Underlying the "strategy-specific" model are the implicit assumptions that the two hemispheres are organized differently and that both can participate concurrently and independently in the processing of disparate components of the same stimulus. Evidence of anatomical differences between the two hemispheres in adult (Geschwind & Levitsky, 1968), neonate (Witelson & Paille, 1973), and pre-gestational brains (Wada, Clarke, & Hamm, 1975) has been taken as support for the assumption of differences in functional organization. These post-mortem studies have found that the language mediating areas of the superior surface of the temporal lobe are larger in the majority of cases on the left than on the right.

Although there is precedence for more complex functions to be represented by larger neural areas, structural asymmetries, in and of

themselves, do not necessarily imply that there are intrinsic differences in functional and physiological organization between the hemispheres. Furthermore, one must be cautious when hypothesizing functional differences based on gross anatomy, since Broca's area (a speech mediating region in the left frontal lobe) has been found to be smaller in the left hemisphere than in the right hemisphere (Lemay, 1976; Wada et al., 1975).

The second assumption that the two hemispheres process information in parallel with each other has been most extensively addressed by Dimond (1972). Based on a series of studies, he has concluded that:

The picture of brain function which emerges is that of a two-brain individual in which each half brain analyzes separately the information it receives. The total capacity of the brain is different from that which assumes that it carries out only one function at a time, or that it consists of only a single channel of limited capacity. It is an arrangement in which there is both individuation as well as integration between each half of the system and the other. (p. 287)

Support for the assumption of parallel processing has been drawn from studies of split-brain patients (Nebes, 1974) as well as from findings with normals (Dimond, 1972, 1977). Goodglass and Calderon (1977) studied the concurrent processing of verbal and tonal materials in trained musicians. In this study, a DL task was used in which competing digits sung in competing tonal patterns were presented simultaneously to each ear. In another condition, spoken numbers were superimposed on piano noted and presented to each ear. In both conditions, Ss were asked to report both the digits and the tonal patterns they had heard. A right ear superiority was found for the verbal component of the complex stimulus, and a left ear superiority for the tonal component. These data were

interpreted as suggesting that each hemisphere can encode the components of a complex stimulus for which it is particularly equipped to handle.

One advantage of starting from the position that the two hemispheres are characterized by particular "descriptive systems" is that it enables one to reinterpret behavioral syndromes associated with neurologic insult. Constructional apraxia, for example, is operationally defined as extreme difficulty in the reproduction of drawings, geometric figures, or constructions with sticks and blocks, which cannot be attributed to motor or sensory problems (Benton, 1967). According to the "stimulus-specific" laterality model, constructional deficits should occur following lesions to the right hemisphere, because of the strong visuospatial task demands. The "strategy-specific" model, however, would maintain that this disturbance might occur with lesions to either hemisphere, with the types of errors differing on these constructional tasks, depending on the side of the lesion.

Warrington (1966), who investigated constructional deficits in brain injured patients, found impaired performance in individuals with lesions to the left hemisphere and likewise in those with lesions of the right hemisphere. Close scrutiny of the quality of the deficits and the types of errors that were made showed qualitative differences with respect to lesion side. Warrington (1966), as did McFie and Zangwill (1960), observed that left hemisphere damaged patients made errors with respect to details and that patients with right hemisphere lesions made errors with respect to configuration and spatial organization.

This type of approach is reflected in the thinking of the Russian neuropsychologist Alexander Luria. According to Luria (1973), no psychological-cognitive function is located in a specific, single neural tissue

as a strict localization model might hold. Rather, he argues for a theory of dynamic localization and conceptualizes the brain as consisting of hierarchically organized neural systems. Luria proposes that during any single psychological-cognitive activity, such as reading, various neural zones participate as component parts of a complex "functional system," and each neural zone that is involved contributes a different aspect to the total psychological structure.

To illustrate this concept, Luria (1973) discusses the syndrome of apraxia, which is an inability to make purposeful movements due to brain injury. The ability to make purposeful movements, for example, relies on the conjoint participation of several neural areas which comprise the functional system. Depending on which of these neural areas is injured, the structure of the movement is affected differently. Injury to the post-central cortex may result in a disturbance of finely differentiated movements, whereas injury to other parietal-occipital areas may produce an inability to place the hand in its necessary position in space. Similarly, damage to the basal ganglia or premotor cortex may result in a lack of smooth consecutive organization of hand movements. Damage to other areas affects the structure of the activity in different ways. Consequently, Luria demonstrates that a "syndrome" might arise from diverse lesions to areas involved in a "functional system" and stresses the importance of obtaining careful phenomenological descriptions of the quality of the resulting deficit.

Despite the advantages offered by the approach outlined by Luria (1973), more systematic research must be carried out before making definitive statements about the processing strategies of the hemispheres.

An additional caveat bears on the assumption that there are isomorphic relationships between types of strategies and brain localization. Despite Wgotsky's (1965) and Luria's (1973) stand on this issue, evidence about strategies tends to be inferential and it cannot always be affirmed that differential successes or failures are the result of the application of different strategies.

### Current Research Directives in Laterality

One popular takeoff on the idea of cerebral asymmetry of function has been the recent trend to identify individuals as having a "left" or "right" hemisphere cognitive mode, based on the extent that they exhibit characteristics presumably associated with the left and right hemispheres (Arndt & Berger, 1978). It has been assumed that people who tend to be verbal and analytic use their left hemispheres more extensively and efficiently, while the reverse has been assumed for individuals who favor visuospatial or gestalt approaches. In part, this inferential leap has been based on reports that there is less alpha activity in the left hemisphere during performance on verbal tasks and less alpha in the right hemisphere during performance on visuospatial tasks (Ornstein & Galin, 1976).

Investigators have shown that various paper-and-pencil tests of preferred cognitive mode (i.e., verbal-analytic versus spatial-gestalt) can discriminate between individuals who favor one approach over another, as defined by their occupational choice, i.e., lawyers versus artists (Galin & Ornstein, 1974). However, there is little direct evidence to support the claim that an individual's preferred cognitive mode is actually related to asymmetry of cerebral functioning. In fact, recent research addressing this problem has found no correlation between

behavioral measures of laterality (i.e., DL or VHF tasks) and preferred cognitive mode (Arndt & Berger, 1978). Similarly, there has been little evidence supporting a relationship between cerebral laterality and occupational choice.

Even more radical have been proposals (Galin, 1974) that the emphasis on verbal-analytic cognitive approaches, characteristic of Western culture and thought, mirrors an over reliance on left hemisphere functions. This has been contrasted with the more intuitive, esoteric approaches of Eastern philosophies, which presumably reflect a disproportionate emphasis on right hemisphere functions. This line of reasoning has been further extended to the realm of psychotherapy. Galin (1974) has argued that the goal of psychotherapy should involve the better integration of left and right hemisphere modes, with therapists serving the role of the corpus callosum. While it is not argued that such syntheses of approaches prove humanistically valuable, there is, again, no evidence for the speculative proposal that different cultural and philosophical orientations actually reflect differences in cerebral laterality of function.

Clearly, what is strongly needed are new directives in research. Much recent work by Dimond and associates (Dimond, 1972, 1975; Dimond & Beaumont, 1971, 1972) has stressed the importance of interhemispheric sharing of cognitive load and emphasized that the nature of information flow within and between the hemispheres should be carefully scrutinized. There appears to be some major disagreement between those who think of information flow as primarily competitive (Levy, 1969, 1974) and those who see the double brain as primarily a cooperative arrangement (Dimond, 1972, 1975).

Equally salient and controversial have been recent proposals of systematic variations in topological brain organization among particular groups of individuals, i.e., males versus females, right-handers versus left-handers. There is current disagreement as to the existence of possible sex differences in the cerebral representation of language and nonlanguage functions. Some researchers postulate that females have a more pronounced separation of linguistic and visuospatial functions into the left and right hemispheres, respectively (Buffery & Gray, 1972), whereas others view bilateral language representation as being more characteristic of females than males (Lake & Bryden, 1976; McGlone & Davidson, 1974; McGlone, 1976, 1978). Still others have argued that such purported sex differences are artifactual and actually related to differences in maturation rates for acquiring various developmental milestones, regardless of sex (Waber, 1976).

Similarly, the cortical representation of language functions among left-handers is far from being resolved. Although the vast majority of right-handers (>95%) are thought to have speech and language functions lateralized primarily to the left hemisphere, the nature of such organization among left-handers remains enigmatic. Some theories postulate bilateral representation of language in left-handers (Hecaen, 1976), other theories postulate a more variable, though unilateral representation (Penfield & Roberts, 1959; Warrington & Pratt, 1973), whereas others view left-handers as being a heterogeneous group consisting of at least three different subtypes: those with bilateral language, those with left hemisphere language, and those with right hemisphere language (Levy, 1974; Satz, 1978a, 1978b). Recent research has attempted to specify the actual proportions of left-handers who might fall into each of these three subtypes (Satz, 1978a, 1978b).

To a large extent, investigators of sex and handedness differences among normal individuals have used findings from various lateral sensory tasks (i.e., DL, VHF, and dichotomous stimulation) to buttress their arguments for a relationship between such variables and topological brain organization. Individuals have been classified into left hemisphere, right hemisphere, or bilateral speech groups on the basis of the direction and magnitude of perceptual asymmetries obtained on these laterality tasks. Thus, right channel superiorities for verbal stimuli have been interpreted as reflecting left hemisphere dominance for language and speech. Left channel, or even reduced right channel, superiorities for nonverbal stimuli have been thought to indicate right hemisphere dominance or less complete lateralization of language and speech functions to the left hemisphere.

The problems with this approach are twofold. The first problem relates to the actual validity of using perceptual asymmetries to classify individuals into one hemisphere speech group or another and has recently been addressed by Satz (1977). According to Satz (1977), the probability of left brain speech in a right-hander, given a right ear advantage (REA) on dichotic listening is approximately 97%. Thus, researchers can, with a remarkably high degree of confidence, assign right-handers with a REA to a predicted left brain speech group. However, the probability of right brain speech, given a left ear advantage (LEA) on dichotic listening, is abysmally low (i.e., 10%). Consequently, when right-handers are predicted to have right hemisphere speech based on a LEA, they are incorrectly classified 90% of the time. Satz (1977) warns that ". . . if the validity of these laterality measures is questionable, then we shall begin to construct theories which have no referents in the state of nature" (p. 211).

The second problem involves several unresolved, critical questions as to the underlying neurophysiological mechanisms which account for perceptual asymmetries obtained on laterality tasks. At least two such mechanisms have been proposed to explain the occurrence of perceptual asymmetries in normal right-handed individuals. Intrinsic to both is the assumption that perceptual asymmetries reflect underlying asymmetric functions of the two hemispheres for processing language and nonlanguage stimuli.

One, however, is a structural account based on a pathway-transmission model, which states that stimuli are better processed if they have direct access to the hemisphere most specialized for processing them. The two foremost proponents of this model have been Kimura (1961, 1967) and Moscovitch (1973). The form of their argument is as follows: when verbal inputs are presented to the right channel, they are projected directly, via contralateral pathways, to the left hemisphere which is most adept at processing verbal stimuli. Verbal inputs presented to the left channel, however, must traverse an indirect pathway from the left ear or VHF to the right hemisphere and then across the corpus callosum (or other interhemispheric commissures) to the left "language" hemisphere. Consequently, left channel inputs are less readily perceived because of the greater amount of time taken by the indirect route and because the input is degraded in terms of strength or clarity as it crosses the callosum. The converse is argued for the input of nonlanguage stimuli.

Until approximately eight years ago, the pathway-transmission model was widely accepted by neuropsychologists as providing the most cogent, parsimonious explanation of perceptual asymmetries. For the most part, it made good sense to do so, based on the large number of studies which

seemed to support this model. Kinsbourne (1970a), however, challenged this position on the grounds that it could not account for the magnitude of perceptual asymmetries obtained on laterality tasks. He argued that callosal transfer of information involved only one extra synapse taking approximately four milliseconds. This interval (four milliseconds) did not seem to be sufficiently long enough to result in such large between-channel discrepancies as obtained on laterality tasks. Similarly, he further argued that the pathway-transmission model could not account for intra-individual variations in the magnitude of perceptual asymmetries during performance across a particular laterality task.

Taking a more functional approach, Kinsbourne (1970a) postulated that perceptual asymmetries were induced by differential changes in activation or attention between the hemispheres. Asymmetric hemispheric activation not only made the hemisphere more receptive to incoming stimuli, but also produced changes in physical orientation contralateral to the activated hemisphere. Thus, when the left hemisphere was activated, it directed attention to the right side of body space such that stimuli presented there were better perceived than those occurring in the left side of space. The converse occurred with activation of the right hemisphere.

Central to Kinsbourne's attentional model was the hypothetical construct of "cognitive set." An individual's verbal or nonverbal cognitive set was relegated the role of actually "priming" or activating the left and right hemispheres, respectively. A cognitive set was itself induced by various pre-task and task instructions which presumably set up "expectations" as to the type of processing that would be required, i.e., verbal or nonverbal.

Thus, according to Kinsbourne's attentional model, an individual's cognitive set not only induces perceptual asymmetries, but also modulates the magnitude of these asymmetries by differentially activating the two hemispheres. This contrasts with the pathway-transmission model which maintains that perceptual asymmetries arise because of the direct access of stimulus input to the target hemisphere. While both perspectives might be correct, it is necessary to more carefully scrutinize the assumptions underlying each as well as experimental evidence which might differentiate between these two models.

### The Pathway-Transmission Model of Perceptual Asymmetries: The Direct Access Hypothesis

The initial purpose of Kimura's (1961) pathway-transmission model was to account for the REA obtained on dichotic listening tasks. It was subsequently extended to explain perceptual asymmetries with nonverbal stimuli as well as with other laterality tasks. Central to the initial formulation of this model was the assumption of total asymmetry of perceptual functions between the hemispheres. This assumption was later modified in light of evidence suggesting that some residual low level language skills were mediated by the right hemisphere (Gazzaniga & Hilliard, 1971; Zaidel, 1978).

The modified version of the pathway-transmission model is consequently based on a four-part argument which postulates that: (a) there are hemispheric differences in the processing of verbal and nonverbal materials; (b) contralateral sensory-hemisphere pathways are stronger or more "prepotent" than ipsilateral connections; and (c) information is relayed between the hemispheres via the corpus callosum and other neocortical commissures. From this, it is deduced that stimuli are better

perceived when presented to the ear, VHF, or hand which has the most direct access to the hemisphere specialized for processing these materials.

The critical test of any model is how well it can predict experimental outcomes in research designed to test hypotheses generated from the model. The question, therefore, for the pathway-transmission model is what experimental evidence exists for the specific hypothesis that stimuli are more readily processed when presented to the ear, VHF, etc., having the most direct access to the target hemisphere. Support for this hypothesis has been drawn from a massive body of literature over the past 15 years finding that verbal and nonverbal stimuli are recalled, recognized, and responded to more quickly when presented contralateral to the target hemisphere (See Tables 1-5).

A major problem which arises, however, is one of logistics. Laterality findings which are consistent with a pathway-transmission model are the same ones which Kinsbourne's attentional model would predict. Consequently, one cannot differentiate between these two models of perceptual asymmetries based on findings from traditional laterality paradigms, since both are compatible with these data.

This line of argument, of course, does not speak to the integrity of the direct access hypothesis per se. Two types of recent studies, however, report results that are incompatible with a simple wiring account of perceptual asymmetries in terms of sensory input-hemisphere output connections. The first type is concerned with characterizing laterality effects as a "side of stimulus entry" or spatial position phenomenon and the second deals with the extent that laterality effects can be modified and altered by contextual variables.

Goldstein and Lackner (1974) have demonstrated that laterality effects on dichotic listening may be influenced by Ss' perceived spatial orientation. In this study, the usual REA was obtained for consonant-vowel syllables (CVs) in a dichotic recall task. If, however, their Ss wore prisms which displaced their visual environments to the left, then the REA was substantially reduced. Prisms that displaced visual environments to the right significantly increased the magnitude of the REA.

Similarly, Morais and colleagues (Hublet, Morais, & Bertelson, 1976; Morais, 1975; Morais & Bertelson, 1975) have found a right-sided advantage for divergent verbal messages that are presented through loudspeakers situated to the left and right of the S's median plane. This right-sided advantage can be totally abolished by misleading Ss about the position of the loudspeakers. In one study, Morais (1975) placed "dummy" loudspeakers that were visible to the Ss in left and right hemispace. The loudspeakers from which the divergent messages actually originated were hidden from the Ss. When both the real and dummy loudspeakers were placed 90° to the left and to the right of the median plane, a marked right-sided advantage was found for the recall of CVs. However, when the dummy loudspeakers were moved to 45° left and right of midline, no advantages occurred for the CVs which, in actuality, were still presented from the concealed loudspeakers located 90° to the left and to the right of midline.

Furthermore, Anzola and coworkers (Anzola, Bertoloni, Buchtel, & Rizzolatti, 1977) have demonstrated that choice reaction time (RT) asymmetries to lateralized visual stimuli are dependent upon the spatial stimulus-response compatibility of the stimulus and the responding hand.

When lateralized stimuli were presented to Ss with hands crossed and uncrossed, faster RTs were obtained by the hand positioned in the same visual space as the stimulus. For example, if the hands were uncrossed such that the left hand was on the left side of the body and the right hand on the right side of the body, then stimuli presented to the LVF were responded to faster by the left hand and stimuli in the RVF were responded to faster by the right hand. If, however, the hands were crossed, such that the left hand was on the right side of the body and the right hand on the left side, then stimuli presented in the LVF were responded to faster by the right hand (in left body space) and stimuli in the RVF were responded to faster by the left hand (in right body space).

These findings are incompatible with a simple anatomical wiring account of perceptual asymmetries. Instead, they implicate the importance of spatial localization mechanisms in producing laterality effects and suggest that the routing of signals to the hemispheres depends, at least in part, on some decision as to the spatial origins of signals. While it is not the present purpose to speculate on the nature of such localization mechanisms, one can readily see that in all traditional laterality paradigms, the ear or VHF of stimulus input is perfectly confounded with the direction of stimulation (Kinsbourne, 1975; Morais, 1975). In some respects, these findings are more consistent with an account of lateral asymmetries in terms of hemispheric specialization and attention.

The effects of contextual variables on perceptual asymmetries have been investigated by a number of researchers. Several early studies have shown that dichotically presented vowels typically exhibit no ear advantages, in contrast to the right-sided advantage obtained with

consonants. When, however, these vowels are embedded within either linguistic or nonlinguistic contexts, these stimuli then exhibit right or left ear asymmetries, depending on the context in which they occur (Haggard, 1971; Spellacy & Blumstein, 1970). More recent studies have also examined the effects of various task and contextual factors on perceptual asymmetries, although discussion of these findings will be deferred until the section on attentional asymmetries.

The import of the preceding findings is that a structural anatomical pathway model cannot easily accomodate the effects of changing context or spatial orientation. While evidence exists which is consistent with this model, there is a body of data which cannot be accounted for by a simple input-output wiring explanation. Logically, confirmation of the direct access hypothesis leads one to accept the postulates upon which it is based. However, failure to confirm this hypothesis across a wide spectrum of data leaves one uncertain as to the source of the deductive error, i.e., either the postulates themselves are faulty, or the stated postulates are correct, although other relevant assumptions have been overlooked and excluded from the model.

For the most part, there is considerable empirical evidence in favor of the three postulates of the pathway-transmission model. Despite some controversy over the suppression of ipsilateral auditory sensory pathways during dichotic listening<sup>1</sup>, most investigators have accepted the assumption that contralateral sensory-hemisphere pathways are stronger or more "prepotent" than ipsilateral connections (Postulate b). This has been based, to a large extent, on findings that evoked responses to lateralized stimuli are faster or larger in amplitude over the contralateral than ipsilateral hemisphere (Majkowski, Bochenek,

Bochenek, Knapiefijalowska, & Kopec, 1971; Matsumiya, Tagliasco, Lombrosco, & Goodglass, 1972; Mononen & Seitz, 1977). Given the rather robust support for the postulates underlying the pathway-transmission model leads one to believe that perhaps some critical information and assumptions have not been considered and incorporated into this model of perceptual asymmetries.

Before turning to a discussion of Kinsbourne's attentional-cognitive set model, a brief overview of various neurophysiological and neuropsychological models of attention will be provided.

### Attention

#### Definition and Measurement of Attention

The functional significance of the construct "attention" in academic psychology has been to provide a label for some of the internal mechanisms that determine the significance of stimuli, thereby making it more possible to predict behavior. In this context, behavior represents the end result of the organizational and information processing aspects of brain function consequent to external stimulation. Attention is a hypothetical construct which is thought to modulate the manner in which information is processed and organized in the brain.

Despite the sporadic emphasis on attention by psychological investigators over the past century, a voluminous amount of research has addressed this topic during the last ten years. This literature can be roughly divided into studies which have dealt with this problem by one of two main approaches (Posner, 1976). First are studies of information processing in simple tasks which have given rise to psychological-cognitive theories of attention. This approach has fallen primarily within the domain of cognitive psychology and has been of little interest to

neuroscientists because it has not addressed neural mechanisms underlying attention. Second are physiological studies involving lesions of particular brain areas, recordings of autonomic activity, measures derived from the electroencephalogram (EEG), and responses of one or a small group of cells at some specific level of the nervous system. This approach has given rise to neurophysiological and neuropsychological models of attention and arousal, with particular emphasis on delineating brain systems which are important for mediating these processes.

A third approach, which will not be addressed in the present overview, has involved the incorporation of the concept "attention" into more molar accounts of behavior and motivation. This approach has been characterized by behavioral research which has discussed such issues as adaptation level (Helson, 1964), intrinsic motivation (Hunt, 1965), and expectancy (Bruner, 1957).

While it is beyond the scope of the present discussion to address in depth the literature on attention, an overview of the major neurophysiological and neuropsychological models will be provided in the following section. This will be followed by discussion of Kinsbourne's attentional model of perceptual asymmetries. To insure a common frame of reference, attention will be conceptualized as consisting of three components, according to the taxonomy of Posner and Boies (1971): an intensive component (arousal, activation, alertness); a selective component (selective attention); and a limited central processing component.

The intensive component, most frequently referred to as arousal or alertness, is the general nonspecific receptivity of the organism to incoming stimuli. While being "awake" implies that an organism is

in some basal state of arousal, the term "arousal reaction" denotes a specific intensification of this basal level and has been operationally defined in terms of neurophysiological concomitants that result from the input of strong painful stimuli (Lynn, 1966). The types of stimuli that produce arousal have been studied extensively and labelled by Berlyne (1960) as collative variables. These stimulus properties include, among others, those of novelty, incongruity, and complexity.

The selective component, i.e., selective attention, refers to the selective guiding effect that is superimposed upon the arousal reaction. Any time one incorporates into their model of arousal an analyzing mechanism via which aspects of stimuli or responses of one kind are selected, they are, by definition, referring to attention. Sokolov's (1963) model of the orienting response, which is based on an arousal mechanism and a mechanism which determines whether stimuli are significant, represents perhaps the most primitive form of attention. An organism can be aroused without being attentive, although the converse is never true. The relationship between arousal and attention has been described as an inverted U-shaped curve, in which performance deteriorates at both low and high levels of arousal (Tecce, 1972).

The selectivity component of attention has been divided into two further components: involuntary selective attention and voluntary selective attention. Involuntary selective attention refers to the "involuntary" surge of activation that follows presentation of novel or significant stimuli, including those that have acquired significance through learning. In this case, the organism has little volitional control over this biological response. With voluntary selective attention, however, the organism consciously chooses to attend to stimuli because they are

relevant to a task he has chosen to perform. Studies of voluntary selective attention have been classified according to what Ss are required to select (Treisman, 1969): stimuli from a particular source, targets of a particular type, specific stimulus attributes, or responses of a particular type.

Finally, a third sense of attention as used in current psychological research relates to the idea of a limited central information processing capacity. Since various stimulus properties also define the concept of "information" as used in the study of communication systems, it has become customary to treat organisms subject to arousal and attention as "information processing systems." Various models have been proposed which attempt to account for the manner in which information is processed and the role of attention has been incorporated into these models (Kahnemann, 1973; Posner, 1976).

One of the most critical issues facing investigators of attentional components of behavior concerns how these phenomena are measured. Researchers have variously used measures of brain electrical activity including the EEG, contingent negative variation (CNV), evoked potential (EP), recordings of autonomic activity such as the galvanic skin response (GSR), and heart rate (HR), and more overt behavioral indices such as reaction time (RT). While the distinction is not entirely clear-cut, electrophysiological measurements are generally used to index arousal, whereas more behavioral performance measures (i.e., accuracy and/or speed of task performance) are used to index selective attention. Although recent research suggests that subtle measures derived from the EEG such as the  $P_{300}$  wave of the EP and the CNV, are correlated with attention (Picton & Hillyard, 1974a, 1974b; Tecce, 1972), attention is

generally inferred from the manner in which experimental task performance is affected. In this context, attention is a hypothetical construct which can only be defined in operational terms such as task performance.

In most cases, electrophysiological measures have been shown to be reasonably accurate and sensitive to variations in the level of arousal or alertness. However, one major problem concerns the implicit assumption that arousal is unidimensional and that all indices of it should move in the same direction as arousal fluctuates. This is based, in part, on the work of Lindsley (1960), who demonstrated that as an individual moves from a state of least to most arousal, there is a corresponding increase in the frequency of EEG rhythms from high amplitude slow waves to low amplitude fast waves (i.e., beta).

Difficulty with the unidimensional arousal assumption is reflected in studies which have examined the correlations among various electrophysiological measures of arousal. Graham and Clifton (1966), for example, found that none of the correlations among a variety of these measures exceeded a value of .5, with the highest correlation between EEG and HR.

Furthermore, there is sometimes found a dissociation between EEG activation and behavioral arousal, in that the EEG may reflect activation while the organism's behavior clearly does not, or vice versa. This is noted during paradoxical sleep (Dement & Kleitman, 1957) and in the "sleeping" EEG records of behaviorally awake animals that have been given various drugs. Bradley and Key (1958) demonstrated that animals administered atropine showed slow brain wave activity on the EEG, although they were behaviorally awake. Conversely, Feldman and Waller (1962), who lesioned hypothalamic nuclei in cats, found that these behaviorally comatose animals produced "active" EEG patterns.

## Neuropsychological Models of Attention

Neuropsychological models of attention have been closely linked to the neurophysiological work on the brainstem reticular activating system (RAS). This system is a multisynaptic neuronal network extending the reticular core of the brainstem, receiving inputs from major sensory systems, and having ascending and descending connections to major brain areas (Thompson, 1967). In an early landmark study, Moruzzi and Magoun (1949) hypothesized that the RAS was critical for mediating arousal via its activating influence on the cerebral cortex. Support for this hypothesis was initially drawn from studies finding that electrical stimulation of the RAS produced cortical EEG activation, as well as autonomic and behavioral components of the arousal reaction (Moruzzi & Magoun, 1949).

Stimulation of the RAS has also been shown to exert enhancing effects on task performance. Fuster (1958), who trained monkeys on a stimulus discrimination task, found that electrical stimulation of the RAS resulted in faster discriminative RTs and more correct responses on this task. In a human analogue study, Lansing, Schwarz, and Lindsley (1959) measured RTs to light flashes that were sometimes preceded by an auditory warning stimulus (WS). They found that reduced RTs in the WS condition were correlated with EEG activation.

In contrast to these stimulation studies, ablative paradigms have found that lesions to the ascending components of the RAS attenuate EEG activation (Lindsley, Schreiner, Knowles, & Magoun, 1950). The behavior of these lesioned animals is characterized by hypokinesia and coma.

While the ascending "reticular-cortical" connections were initially sufficient for understanding arousal and sleep-wakefulness cycles, they could not account for more complex components of attention. Since higher

cognitive functions involved in selective attention seemed to have emerged with the development of the neocortex, it was logical to hypothesize that the neocortex had functional connections and influence on the RAS. This inference led French and coworkers (French, Hernandez-Peon, & Livingston, 1955) to investigate "cortical-reticular" connections. As predicted, stimulation of cortical areas projecting to the RAS not only produced evoked responses of the RAS, but also induced behavioral and autonomic components of the arousal reaction.

The foremost investigator to tie together this knowledge of cortical-reticular influences into a model of attention was Sokolov (1963). He proposed an attentional model based on the orientation reaction. This refers to a set of behaviors, both neurophysiological and more overt, which is prompted by the presentation of a novel or biologically significant stimulus. The most conspicuous aspect of the orienting response (OR) is that the organism turns (i.e., orients) toward the source of stimulation. In addition to behavioral turning, various neurophysiological concomitants of increased arousal occur, including the lowering of sensory thresholds, EEG desynchronization, HR deceleration, increased GSR, a pupillary response, and vasodilation of the head. The functional significance of all these concomitants of the OR is to make the organism more receptive to incoming stimuli ("attentive") as well as to prepare the organism for action ("intention").

Sokolov's attentional model consisted of two formal components, an analyzing mechanism which determined whether stimuli necessitated an OR and another mechanism via which the OR could be initiated. The analyzing mechanism was located in the cortex and the "activating" mechanism in the brainstem RAS. According to Sokolov, the neurophysiological basis

of the OR was a cortico-reticular feedback loop involving the RAS and neuronal templates in the cortex, which were representations of stimulus parameters. When sensory input did not match these neuronal templates, i.e., were significant or novel, the cortex sent excitatory discharge to the RAS via cortico-reticular pathways. This, in turn, activated the RAS which further activated the cortex via reticular-cortical pathways. To the extent, however, that there was a match between incoming stimuli and cortical templates, the OR was inhibited or habituated.

Sokolov further delineated two components of the OR, the localized and generalized components, which were mediated by the thalamic and mesencephalic RAS, respectively. These two components paralleled the distinction made by Sharpless and Jasper (1956) between the phasic and tonic arousal reactions. The tonic/generalized component involved diffuse EEG activation, slow recovery time, and rapid habituation. The phasic/localized component was characterized by activation of a discrete cortical area, fast recovery time, and slow habituation. Thus, any stimulus that elicited an OR could be described in terms of these three parameters: generalization-specificity; rate of recovery time, and rate of habituation. The generalization-specificity parameter referred to the extent that stimulus presentation induced diffuse versus discrete cerebral activation. The recovery time parameter referred to the temporal duration of activation following a single stimulus presentation, and habituation referred to the diminished activation which occurred with repeated presentation of a stimulus.

The major import of Sokolov's (1963) model was that it integrated knowledge of cortical and subcortical mechanisms into a uniform theory of attention. It further generated an abundance of research which greatly

enhanced the understanding of simple attentional phenomena. The limitations of this model, however, was that it attempted to explain only two components of attention: arousal and involuntary selective attention. It is easy to see how one might extend the general trappings of this model to explain more cognitively complex aspects of selective attention.

Other neurophysiological models of attention-arousal have included those of Hernandez-Peon (1966), Lacey (1956), Routtenberg (1968), and Pribram and McGuinness (1975). Hernandez-Peon (1966) essentially proposed a model of attention in which selective peripheral gating occurred prior to sensory analysis. According to this model, selectivity was mediated by a reticulofugal inhibitory mechanism which acted on the first sensory synapse. However, no provisions were made for the selection of significant stimuli.

Lacey (1956) proposed a two-dimensional arousal model which distinguished between the "taking in" of stimuli from the environment and the "rejection" of stimuli. He argued that the "taking in" of stimuli corresponded to increased arousal and the "rejection" of stimuli corresponded to decreased arousal. He further postulated an inverse relationship between heart rate (HR) and EEG activation: HR deceleration reflected increased arousal and HR acceleration reflected decreased arousal. The neurophysiological underpinnings of Lacey's reasoning were based on findings that stimulation of the carotid sinus inhibited the nucleus solitarius in the brainstem. This, in turn, inhibited cortical activation, which then improved the probability that stimuli would be rejected.

The major problem with Lacey's formulation is that no objective criteria were provided for determining what was considered "rejectionable"

and what was considered "acceptable." In a convincing article which attempted to synthesize various models of arousal, Graham and Clifton (1966) proposed that Lacey's "taking in" of stimuli was equivalent to Sokolov's OR, and that the "rejection" of stimuli was equivalent to Sokolov's defensive reaction (DR). These authors further argued that HR deceleration represented the cardiac component of the OR. Thus, Lacey's model can best be subsumed under Sokolov's model of the OR.

Routtenberg (1968) proposed an arousal model which attempted to explain those findings which have suggested a dissociation between EEG and behavioral indices of arousal. According to Routtenberg, arousal is a two component process which is mediated by two distinct, though interacting neural systems. One component (Arousal System I) is primarily concerned with producing neocortical desynchronization subsequent to external stimulation and is mediated by the RAS. The second component (Arousal System II) is critical for the maintenance of basic vegetative functions and ". . . provides control of behavior through incentive related stimuli" (p. 51). This system is mediated by the limbic-midbrain regions, particularly the medial forebrain bundle.

According to Routtenberg, the most profound arousal deficits result from extensive lesions involving both neural systems. Lesions to the RAS alone, however, eliminate or reduce EEG activation, although wakefulness of the animal is maintained via Arousal System II. Conversely, lesions to the limbic-midbrain region induce coma or disruption of primary vegetative functions, although EEG activation, mediated by the RAS, may persist.

Based on this line of reasoning, Routtenberg then argues that the EEG-behavioral dissociations observed with atropine administration or

hypothalamic lesions are based on the differential involvement of the two neural systems responsible for mediating arousal. He proposes that atropine primarily suppresses the RAS (i.e., decreased EEG activation), whereas the limbic-midbrain regions are relatively unaffected. These predictions parallel the findings of a "sleeping" EEG in behaviorally awake animals consequent to atropine administration (Bradley & Key, 1958). Routtenberg similarly explains Feldman and Waller's (1962) findings of an "alert" EEG in comatose cats consequent to hypothalamic lesions. In this case, the limbic-midbrain region important for the wakefulness of the animal has been damaged, although the RAS remains intact.

Routtenberg's (1968) delineation of two aspects of arousal and their underlying neural mechanisms represents a critical contribution to the understanding of arousal phenomena. The limitation of this model is that it does not address the mechanisms underlying selective attention.

Pribram and McGuinness (1975) have proposed an extremely complicated model of attention. Like Sokolov (1963), they claim that localized in the brain are "central representations," or memory traces of stimulus configurations. Their model consists of three separate, though interacting attentional control systems which are centered in the amygdala, basal ganglia, and hippocampus, respectively. The neural system centered in the amygdala controls arousal, which they define as a phasic physiological response to stimulus input. These arousal circuits function by modulating serotonergic neurons in the brainstem. The neural system centered in the basal ganglia controls activation, which is defined in terms of a tonic physiological "readiness to respond" or execute perceptual or motor acts. The third neural system, centered in the hippocampus, is concerned with coordinating the

relationship between arousal and activation. This coordinating activity is defined as requiring effort and involves ". . . uncoupling stimuli from responses so that appropriate changes in central representations can occur" (p. 111). According to Pribram and McGuinness, such changes in central representations can be conceived as changes in state, set, or attitude.

After defining the three basic parameters of this model, Pribram and McGuinness (1975) assert that arousal, activation, and effort are differentially involved in various activities. They maintain that the OR involves arousal, but not activation, vigilant readiness to respond involves activation, but not arousal; the DR involves both arousal and activation; when neither activation or arousal are present, behavior is automatic in that stimulus-response contingencies are direct and without intervention from any of the attentional control systems. The latter is called "automatized" behavior.

Pribram and McGuinness (1975) further attempt to explain more cognitively complex aspects of voluntary selective attention that are involved in the performance of problem solving tasks. They draw a distinction between "categorizing tasks" and "reasoning tasks." They define "categorizing tasks" as involving a response to some invariant combination of stimuli (i.e., a discrimination judgement). In these tasks, stimuli must be detected, categorized, and responded to, although the critical aspect is stimulus categorization. Based on this line of reasoning, they propose that arousal precedes activation in stimulus categorization tasks.

In "reasoning tasks," stimulus events are variable, but computable (i.e., arithmetic problems). According to Pribram and McGuinness,

"reasoning problems" involve an "uncoupling" of attention from the immediate stimulus variables. In this case, attention is voluntary and initiated by the organism. They consequently propose that activation precedes arousal in "reasoning tasks".

While many of Pribram and McGuinness' arguments seem rather vague, perhaps the most important aspect of their model is the explicit distinction drawn between "attention" (called arousal in their model) and "intention" (called activation) which are presumably mediated by different brain regions. This parallels the distinction made by Sokolov (1963) in his description of the OR as making the organism more receptive to incoming stimuli (attentiveness) and preparing the organism for action (intention). For Pribram and McGuinness, attention refers to the visceral-autonomic components of the arousal reaction that facilitate stimulus receptivity and categorization. Intention encompasses not only somato-motor responses to stimuli, but also includes behaviors involved in an organism consciously directing his cognition and behavior.

Even within the realm of information processing models of attention, the distinction between attentiveness and intention is implicitly drawn. Two general types of cognitive theories have dominated information processing models of attention: those that view information processing as being serial and limited by some filtering stage or bottleneck (Broadbent, 1958; Deutsch & Deutsch, 1963) and those proposing that information can be variably allocated among diverse, parallel channels (Kahnemann, 1973). In Broadbent's (1958) filter model, attention plays the role of "setting the filter" to select a certain class of stimuli and to reject others. This contrasts with the filter model of Deutsch

and Deutsch (1963) who propose that attention determines response selection, i.e., it prevents the initiation of more than one response at a time and "selects" the response that best fits the requirements of the task. Kahnemann's (1973) variable allocation model, on the other hand, incorporates both the notion of a stimulus selection stage and that of a response selection stage.

The distinction between attention and intention has interesting implications on both neurophysiological and behavioral levels. Based on the work of Sokolov (1963), Routtenberg (1968), and Pribram and McGuinness (1975), it appears that arousal is mediated by a complex system involving the RAS and limbic-midbrain regions. Attentiveness to stimuli probably involves cortical systems, whereas intention (i.e., readiness to respond) involves basal ganglia-frontal systems. These three systems can be viewed as functionally interactive and interdependent in the normal individual, such that he is appropriately alert, attentive, and intentionive. Discrete lesions to any one of these systems should result in qualitatively different types of attentional deficits.

On a psychological level, it seems reasonable that an individual can be attentive to stimulus characteristics, without necessarily being intentionive, i.e., organizing one's behavior so that information conveyed by the stimulus is appropriately acted on. Since, however, attentiveness is generally inferred from task performance, experimental paradigms for behaviorally differentiating between attention and intention in normal adults are not immediately apparent.

Recent findings with neurologically impaired individuals suggests that such a distinction can be made, however. Parkinson patients, who have chemical lesions to the dopaminergic systems in the basal ganglia,

are clinically described as being hypokinetic and having difficulty initiating action (intention). Their RTs to simple stimuli are significantly slower than those of matched patient controls (Heilman, Bowers, Watson, & Greer, 1976). However, presentation of warning stimuli significantly reduces the RTs of the Parkinson patients. This RT reduction with WS is proportionate to that obtained with matched controls, suggesting that Parkinson patients are attentive, without being equally intentional.

What is not entirely clear is whether an individual can be intentional without being attentive. Equally unclear is whether the attentional-intentional systems are differentially mediated by the two cerebral hemispheres, i.e., whether each hemisphere has relatively independent attentional-intentional neural systems. Since cortical systems involved in the processing of linguistic and nonlinguistic stimuli are asymmetrically represented in the left and right hemispheres, one might hypothesize that verbal and nonverbal materials asymmetrically activate and prepare the hemispheres for action. This is essentially the basis of Kinsbourne's attentional model of perceptual asymmetries.

#### An Attentional Model of Perceptual Asymmetries: The Cognitive Set Hypothesis

Kinsbourne's attentional-cognitive set model (1970a, 1975) represents an attempt to account for intra-individual variability in the magnitude of perceptual asymmetries obtained on various lateral sensory tasks. It further attempts to explain the difficulty in replicating a number of laterality effects, especially those purporting to underlie right hemisphere advantages. Kinsbourne argues that the difficulty in obtaining "right hemisphere" effects is largely related to the fact that individuals

frequently adopt implicit verbal "cognitive sets" which tend to mask or diminish clear cut left-sided perceptual asymmetries.

Kinsbourne's model of perceptual asymmetries is based on a number of provocative assumptions which, for the most part, have not been addressed empirically. Because of the complexity of his model, it can be best conceptualized as consisting of two levels, which, when combined, generate an hypothesis concerning the basis of perceptual asymmetries. The first level attempts to describe "what happens" when one hemisphere or the other is asymmetrically activated and is based on two assumptions stating that: (a) there is an equal, interdependent balance of activation-attention between the hemispheres, such that when one hemisphere is activated, the other is hypoaroused; and (b) each hemisphere controls or directs attention to the contralateral side of body space. From this, it is deduced that activation of one hemisphere induces increased receptivity of that hemisphere for incoming stimuli, regardless of their verbal-nonverbal dimensions. Furthermore, hemispheric activation produces shifts in physical orientation contralateral to the primed hemisphere, so that stimuli presented in the contralateral side of space are better perceived.

The second level of Kinsbourne's model attempts to explain the manner in which or "how" one hemisphere or the other can be asymmetrically activated and is based on the following assumptions: (a) there are hemispheric differences in processing verbal and nonverbal materials; (b) stimuli or tasks that call for the specialized processing of a particular hemisphere asymmetrically activate the target hemisphere; and (c) a cognitive set, which refers to the probabilistic expectations that stimuli will be processed in a particular manner or according to a particular

strategy, can be induced by pre-task instructions, task performance itself, or by implicit expectations that the individual brings into the experimental setting. From this, Kinsbourne hypothesizes that verbal and nonverbal cognitive sets can asymmetrically and selectively activate the hemispheres.

Kinsbourne then proposes that perceptual asymmetries arise from the adoption of verbal and nonverbal cognitive sets. According to his reasoning, a verbal cognitive set activates the left hemisphere, so that physical orientation and attention are then directed to the right side of space. Stimuli occurring there are more readily perceived than stimuli presented in the left ipsilateral side of space. The converse occurs with nonverbal cognitive sets.

In this way, findings from traditional laterality tasks, i.e., better perception of verbal stimuli presented to the right channel and better perception of nonverbal stimuli presented to the left channel, can be accounted for by Kinsbourne's model. Since, however, the latter findings are also compatible with the direct access hypothesis, they offer little help for distinguishing between these two models of perceptual asymmetries. Those studies, however, which suggest that laterality effects are related to spatial side of stimulus entry are more consistent with an attentional model.

Experimental support for the cognitive set hypothesis in studies specifically designed to test its predictions have been controversial at best. Not only have the findings themselves been contradictory, but the predictions have been vague and often times loose. One type of prediction generated from this model is that performance on a task which induces a verbal or nonverbal "cognitive set" will affect performance on

concurrent or subsequent laterality tasks by altering either the direction or magnitude of perceptual asymmetries that are obtained on the latter.

This prediction was initially addressed by Kinsbourne and coworkers in a series of experiments (Earl & Kinsbourne, 1975; Kinsbourne, 1970a; Kinsbourne & Bruce, 1975). These investigators found that the silent rehearsal of word lists during a tachistoscopically presented gap detection task resulted in better gap detection in the RVF than LVF. Without the concurrent verbal task, gaps were detected equally well in both VHF's. Hellige (1978) also found that rehearsal of lists during the tachistoscopic recognition of nonverbal figures shifted perceptual asymmetries from the left to the right. In these studies, the performance of the verbal rehearsal task was interpreted as inducing a verbal cognitive set which "primed" the left hemisphere. A summary of the findings of studies which have used "priming" tasks to test the cognitive set hypothesis is provided in Table 7.

Since the direct access hypothesis does not in any straight forward manner predict such effects, findings of altered perceptual asymmetries argue against a pathway model as the sole mechanism responsible for producing perceptual asymmetries. However, some researchers (Gardner & Branski, 1976) have been unable to replicate any of Kinsbourne's original findings with gap detection.

Using a different type of paradigm, Klein, Moscovitch, and Vigna (1976) presented "priming" tasks that were then followed by "target" laterality tasks. Without the "priming" tasks, a LVF superiority was obtained for face recognition and a RVF superiority for word recall. With a verbal "priming" task, however, the LVF superiority for faces

TABLE 7  
SUMMARY OF STUDIES USING "PRIMING" TASKS TO TEST THE  
COGNITIVE SET HYPOTHESIS

Study	Main Task	Priming task	Results
Kinsbourne (1970a)	Gap detection in squares	Rehearsal of 6-word lists	No VHF differences without the priming tasks; Better gap detection in RVF with the priming task
Kinsbourne & Bruce (1975)	Recognition of Vanderplas figures	Rehearsal of 6-word lists	No VHF differences without the priming task; Better recognition in RVF with the priming task
Earl & Kinsbourne (1975)	Gap detection in squares	Rehearsal of 6-word lists	No VHF differences without the priming task; Better gap detection in RVF with priming task
Earl & Kinsbourne (1975)	Gap detection in vertical lines	Rehearsal of 6-word lists	No VHF differences without the priming task; Better detection in RVF with the priming task
Gardner & Branski (1976)	Gap detection in squares	Rehearsal of 6-word lists	Better gap detection in LVF with and without the priming task; No differences in the magnitude of LVF asymmetry between the two conditions
Gardner & Branski (1976)	Gap detection in squares	Rehearsal of 3-word lists	No VHF differences, either with or without priming task

TABLE 7 (cont.)

Study	Main Task	Priming Task	Results
Gardner & Branski (1976)	Gap detection in squares	Listening to music	No VHF differences, either with or without the priming task
Gardner & Branski (1976)	Gap detection in squares	Rehearsal of 3-note melody	No VHF differences, either with or without the priming task
Hellige (1978)	Recognition of Vanderplas figures: 12 point and 16 point figures	Rehearsal of 2-word list	12 point figures: LVF better without priming task and no VHF difference with priming task 16 point figures: no VHF difference without priming task and RVF better with priming task
Kershner, Thomae, & Callaway (1977)	Recall of bilaterally presented digits	Nonverbal fixation Verbal fixation	Nonverbal fixation: LVF advantage for digits Verbal fixation: RVF advantage for digits (No control condition)
Morais & Landercy (1977)	RT to target dichotic digit	Rehearsal of 5-note melody Rehearsal of sentence	Music prime: Right ear RT equal to left ear RT Verbal prime: Right ear RT faster than left ear RT (No control condition)

was abolished. With a nonverbal "priming" task, the RVF superiority for words was significantly reduced. While these findings appear, at first glance, to be consistent with Kinsbourne's model, close scrutiny of this data raises questions regarding the manner in which the perceptual asymmetries were altered.

Kinsbourne's model, which predicts that verbal priming activates the left hemisphere, also predicts vis à vis the assumption of reciprocal hemispheric balance of attention, that the right hemisphere should be "hypoactivated." Consequently, a verbal priming task should alter perceptual asymmetries on a nonverbal laterality task by increasing recognition accuracy in the RVF and decreasing recognition accuracy in the LVF. This was only partially confirmed by Klein et al.'s data (1976). Their findings indicated that while the verbal priming task did, in fact, increase accuracy of facial recognition in the RVF, no decrease in accuracy was found in the LVF. A similar pattern occurred with the nonverbal priming task.

Another type of prediction generated from the cognitive set hypothesis deals with the effects of randomly intermixing verbal and nonverbal stimulus trials in a laterality task. According to Kinsbourne (1970), it should be difficult for a S to develop a clearcut cognitive set for the appropriate type of stimulus on each trial of such a randomly mixed list. Consequently, he has predicted that both verbal and nonverbal laterality effects will be diminished when the two types of stimuli are randomly mixed. Hellige (1978), on the other hand, has argued that in such paradigms, Ss might be "biased" to emphasize the processing of one type stimulus more than the other. In this case, Hellige predicts that the same laterality pattern should occur for all types of stimuli

in a randomly mixed paradigm, i.e., all right-sided, all left-sided, or no asymmetries. One problem with both Kinsbourne's and Hellige's predictions are that no objective criteria are provided for estimating what type of laterality patterns might emerge.

Findings from studies using the intermixing paradigm (See Table 8) have been contradictory and subject to methodologic criticism. Some researchers have not included the necessary "pure-list" versus "mixed-list" comparisons, and conflicting interpretations have resulted. These investigators (Berlucchi, Brizzolara, Marzi, Rizzolatti, & Umiltà, 1974; Dee & Hannay, 1973; Geffen, Bradshaw, & Nettleton, 1972; Kallman, 1978) have found that perceptual asymmetries for verbal and nonverbal stimuli do occur in a mixed-list paradigm, although these studies have not included conditions in which only verbal or nonverbal stimuli were presented. Other investigators (Donnefeld, Rosen, MacKacey, & Curcio, 1976; Hellige, 1978) have reported alterations in perceptual asymmetries when pure-list versus mixed-list comparisons were made. In these studies, the left-sided advantages for nonverbal stimuli obtained in the pure-list conditions were either attenuated or shifted to the right, whereas the right-sided asymmetries for verbal stimuli remained intact and unaffected.

Other laterality experiments have tested the cognitive set hypothesis by cueing Ss prior to stimulus presentation as to either the side of stimulation or the type of required processing, i.e., Name versus Physical Identity (Geffen et al., 1972; Hellige, 1978). According to Kinsbourne's model, pre-stimulus cueing should increase the magnitude of perceptual asymmetries. This, however, has not been demonstrated.

The culmination of these contradictory findings regarding cognitive set is that they cast doubt on the validity of Kinsbourne's attentional

TABLE 8  
SUMMARY OF STUDIES USING INTERMIXING PARADIGMS TO TEST THE  
COGNITIVE SET HYPOTHESIS

Study	Verbal Stimuli	Nonverbal Stimuli	Mixed Condition	Pure Condition
Berlucchi et al. (1974)	RT to target letters	RT to target faces	Letters faster in RVF Faces faster in LVF	Not given
Dee & Hannay (1973)	Recognition of let- ters	Recognition of shapes	Letters: no VHF dif- ferences Shapes: LVF better	Not given
Donnefeld et al. (1976)	Recall of consonant- vowels (CVs)	Recognition of pitch contours	CVs: REA Pitch: No ear differ- ences	CVs: REA Pitch: LEA
Geffen et al. (1972)	RT to name identity match (i.e., Aa)	RT to physical identity match (i.e., AA)	Name: RVF advantage Physical: LVF advan- tage	Not given
Hellige (1978)	Recall of words	Recognition of shapes	Words: RVF advantage Shapes: RVF advantage	Words: RVF ad- vantage Shapes: No VHF differences
Kallman (1978)	RT to target CVs	RT to target tone	CVs: faster in right ear Tones: no ear differ- ences	Not given

model of perceptual asymmetries. Failure to confirm the cognitive set hypothesis across a wide spectrum of data again leads one to question whether or not the postulates upon which it is based are faulty. Except for the assumption of hemispheric processing differences, the postulates underlying this model either have not been extensively addressed or the evidence in support of them is ambiguous.

Kinsbourne's speculative assertion that there is a reciprocal balance of attention-activation between the hemispheres was initially advanced as the mechanism underlying unilateral spatial neglect. This syndrome, most frequently observed following lesions to the right hemisphere, is characterized, in its most extreme form, by the total disregarding (i.e., neglecting) of the left side of hemispace, in the absence of primary sensory or motor disturbances. According to Kinsbourne (1970b), unilateral neglect is caused by a hemispheric imbalance in attention: the right hemisphere, because of its lesion, is hypoaroused, thereby resulting in the left hemisphere being hyperaroused. With hyperarousal of the left hemisphere, attention is focally directed to the right side of hemispace, resulting in disregard and inattention to left hemispace.

Although an interesting formulation, there has been no experimental support for this account of the unilateral neglect syndrome. According to Kinsbourne's reasoning, patients with unilateral left-sided neglect should exhibit depressed responses on electrophysiological measures of arousal obtained from the right hemisphere and elevated responsivity from the left hemisphere. This has not been found. Studies of patients with this syndrome have demonstrated a bilateral slowing of the EEG (Watson, Andriola, & Heilman, 1977) and bilaterally depressed GSR's

(Heilman, Schwartz, & Watson, 1978). These findings contradict Kinsbourne's predictions and argue against his hemispheric balance assumption. Similarly, there has been no support for this assumption in individuals who are neurologically intact (Klein et al., 1976). Clearly, this is one assumption which could unequivocally be eliminated from Kinsbourne's model.

The assumptions that hemispheric activation induces a hemispheric state of "perceptual readiness" for stimulus input, as well as produces shifts in physical orientation contralateral to the activated hemisphere is analogous in form to behaviors accompanying the OR described by Sokolov (1963). Instead of the "whole brain" or "whole organism" phenomenon implied by the OR, Kinsbourne postulates that this activational phenomenon can be restricted to one hemisphere or the other.

Support for increased stimulus receptivity by the activated hemisphere has been drawn from reports of lowered sensory thresholds for words exposed to the RVF than LVF (Bryden, 1966; Heron, 1957; Mishkin & Forgays, 1952). The problem with Kinsbourne's formulation, however, is his assertion that with unilateral hemispheric activation, any type of stimulus (verbal or nonverbal) in contralateral hemispace is more easily perceived. At first glance, it is difficult to see how a hemisphere (i.e., the left hemisphere) can process a stimulus (i.e., visuospatial) for which it is not specifically equipped to handle. This, of course, is predicated on the laterality model stating that the hemispheres are differentially organized to mediate specific types of stimuli (i.e., the "stimulus-specific" model). No problem arises if one holds the view that each hemisphere can simultaneously process component parts of any complex stimulus according to its characteristic descriptive systems (i.e., the "strategy-specific" model).

Support for the assumption that hemispheric activation produces shifts in physical orientation (i.e., eye, head, and body turning) contralateral to the primed hemisphere has been drawn from electrical stimulation and ablation studies with monkeys (Crosby, 1953; Kennard & Ectors, 1938) and man (Penfield & Roberts, 1959). Less direct support for this postulate is based on findings from studies of lateral eye movements during reflective thought.

In this paradigm, Ss are presented with either verbal or spatial reasoning problems and their eye movements are then monitored. Kinsbourne (1972) has argued that verbal questions, which presumably produce left hemisphere activation, should induce lateral eye movements to the right because of the functional proximity of left-frontal rightward turning centers. The converse is argued for visuospatial problems. While a number of investigators have been successful at eliciting the predicted gaze shifts (Gur & Harris, 1975; Kinsbourne, 1972; Kocel, Galin, & Ornstein, 1974), this paradigm is replete with critical scoring and methodologic problems, and any findings are probably confounded by the left-right nature of the reading process. Furthermore, Erlichmann and coworkers (Erlichmann, Weiner, & Baker, 1974), in perhaps the most carefully controlled series of these studies, as well as several "unpublished" reports (Lewis, 1973; Tankle, 1975) have been unable to replicate earlier findings that verbal questions induce more gaze shifts to the right and spatial questions more gaze shifts to the left.

"Cognitive set" is a hypothetical construct which has been most extensively addressed by Bruner (1957) and incorporated by Kinsbourne into his model of perceptual asymmetries. It refers to the probabilistic expectations that stimuli will be processed according to a particular

strategy. It is based on the assumption that perception and cognition are selectively organized so that "...new experiences can be assimilated into ordered categories that are meaningful and functionally useful to the individual" (Bruner, 1957, p. 128). According to Kinsbourne (1970a, 1975), every S comes into an experimental situation with an implicit set of expectations, an implicit cognitive set. A cognitive set can be experimentally induced by "pre-task" instructions, as well as by task performance itself. In the latter, stimulus presentation presumably alters the individual's probabilistic expectations about the processing of subsequent stimuli, thereby inducing a particular cognitive set.

At least two issues regarding cognitive set are in need of further clarification. One relates to whether a cognitive set induced by "pre-task" instructions is equivalent to that induced by task performance itself. These appear to be different phenomena within the framework of Kinsbourne's model, since "pre-task" instructions and cueing have not been found to alter perceptual asymmetries, whereas "priming" tasks do appear to affect perceptual asymmetries.

The second issue concerns incorporating "cognitive set" into some neurophysiological model of arousal-attention, since Kinsbourne postulates that it sets up and maintains hemispheric activation. Because "cognitive set" implies more than a transient phenomenon, one might interpret it as roughly corresponding to a form of "tonic" (i.e., long-lasting) activation. This contrasts with the phasic activational response that is "stimulus bound" (i.e., it appears with stimulus presentation and disappears shortly after stimulus onset). With performance of some verbal task, stimulus presentation should produce a brief phasic activational response of the left hemisphere, as well as a more "long-

lasting" or tonic response of the left hemisphere. Although a somewhat simplistic formulation, the latter might represent a neurophysiological analogue of cognitive set as defined by Kinsbourne. This problem has not been experimentally addressed.

Perhaps the most critical assumption of Kinsbourne's model is that stimuli or tasks that require specialized hemispheric processing selectively activate the hemispheres. Support for this postulate has been indirectly inferred from the changes in perceptual asymmetries that are induced by verbal and nonverbal priming tasks (See Table 7). Although there are contradictory findings as to whether the cognitive set hypothesis explains perceptual asymmetries, these studies do not specifically and directly address the hypothesis that verbal and nonverbal stimuli asymmetrically activate the hemispheres.

In summary, Kinsbourne's attentional model suffers serious problems, both in terms of equivocal findings for the "cognitive set" hypothesis and in terms of many of the assumptions underlying this attentional model. Clearly, the notion of hemispheric attentional balance can be eliminated entirely. Likewise, the construct "cognitive set" is ambiguous, especially with respect to how it corresponds to neurophysiological mechanisms. Furthermore, the most critical of all Kinsbourne's assumptions, i.e., that verbal and nonverbal materials asymmetrically activate the hemispheres, has not been adequately assessed.

### Notes

<sup>1</sup>Evidence in favor of the first and third postulates of the pathway transmission model of perceptual asymmetries (i.e., cortical processing differences and intercallosal transfer of information) has been robust. Not everyone has accepted, however, the structural account of the privileged access of information to the contralateral hemisphere (Postulate 2). The visual system poses no problem for this assumption since stimuli in each VHF project directly and exclusively to only one

hemisphere. The problem is the auditory system where each hemisphere receives direct auditory inputs from both ears via ipsilateral and contralateral pathways.

To account for the bilateral wiring of the auditory system, Kimura (1961, 1967) proposed that under conditions of dichotic competition, the ipsilateral ear-hemisphere pathways were rendered essentially non-functional and suppressed by either afferent or central mechanisms. Because of this "ipsilateral occlusion," it was argued that the contralateral ear-hemisphere connections were functionally prepotent during dichotic listening.

While there is little question that dichotic competition is sufficient to produce perceptual asymmetries, there is considerably disagreement as to whether dichotic competition, and ipse facto ipsilateral occlusion is actually necessary. In fact, it does not appear to be essential since RT measures of laterality have demonstrated monaural ear advantages with quite simple verbal tasks (Bever, Hurtig, & Handel, 1976; Catlin & Neville, 1976; Catlin, Vanderveer, & Teicher, 1976; Fry, 1974; Hayden & Spellacy, 1973; Kallman, 1977; Morais & Darwin, 1974; Studdert-Kennedy, 1972). These laterality findings with monaural tasks have led some investigators to seriously question the necessity of postulating the occurrence of ipsilateral occlusion.

An empirical test of this assumption would entail obtaining electrophysiological responses of ipsilateral and contralateral sensory pathways during both dichotic and monaural stimulation. This has not been done. Rather, electrophysiological research conducted thus far has measured cortical evoked responses, from which inferences are made about which pathways (contralateral or ipsilateral) were used (Majkowski et al, 1971; Matsumiya et al., 1972; Mononen & Seitz, 1977). Such findings are equivocal at best in terms of interpretation, as are recent findings with split-brain patients. Milner, Taylor, and Sperry (1968), Sparks and Geschwind (1968), and more recently Zaidel (1974) have shown that, while split-brain patients perform equally well with the left and right ears on monaural identification of digits and letters, their dichotic performance reveals massive, often total left ear loss. Although these findings have been interpreted as support for "ipsilateral occlusion," they, in fact, could be used equally well to support alternative mechanisms, including the attentional model proposed by Kinsbourne (1970a).

## STATEMENT OF THE PROBLEM

The hypothesis that verbal and nonverbal stimuli asymmetrically activate the hemispheres can underlie various attentional models of perceptual asymmetries, whether or not it is the model specifically outlined by Kinsbourne (1970a, 1975). Consequently, the first purpose of the present study was to experimentally address this hypothesis. One way of testing this hypothesis would involve obtaining electrophysiological measures of activation subsequent to the presentation of verbal and nonverbal stimuli. Since, however, the correlations among various electrophysiological measures of arousal are not robust, an alternative and perhaps more functional approach involves the employment of more overt behavioral measures of activation-attention. This is particularly relevant when one considers that there is sometimes a dissociation between EEG indices of activation and actual behavioral manifestations of arousal. In light of these correlational difficulties, a behavioral measure of activation-attention was chosen (i.e., RT) to test the hypothesis that verbal and nonverbal stimuli asymmetrically activate and prepare the hemispheres for action.

One major problem inherent in behaviorally assessing this hypothesis is selecting a paradigm in which findings cannot be interpreted equally well according to both a pathway-transmission and an attentional model. The paradigm that was chosen was an analogue of that used by Lansing et al. (1959), who measured RTs to stimuli that were sometimes preceded by a warning stimulus (WS). These investigators found that faster RTS

obtained in the WS condition, were correlated with EEG desynchronization and suggested that the WS served the function of alerting and phasically arousing the S.

In the present study, manual RTs were obtained to a "neutral" light flash that was preceded by either a verbal or nonverbal WS. Both the light flash and WS were presented at central fixation. The light flash stimuli were considered "neutral" because previous findings have indicated that they are processed equally well by both the left and right hemispheres (Filbey & Gazzaniga, 1969). Earlier studies have also demonstrated that digital movements are mediated by the contralateral hemisphere, i.e., right hand-left hemisphere, and that there are hemispheric processing differences for verbal (i.e., words) and visuospatial (i.e., faces) stimuli (Gazzaniga, 1970).

Consequently, if verbal WS asymmetrically activate and prepare the left hemisphere for action, then manual responses initiated by that hemisphere should be faster than responses initiated by the right hemisphere. According to a material specific activation hypothesis, RTs by the right hand should be faster than left hand RTs when verbal WS are used. Conversely, left hand RTs should be faster than right hand RTs when nonverbal WS are used. Thus, an activational-attentional model would predict RT asymmetries with this paradigm.

What would a pathway-transmission model predict? As discussed previously, this model postulates that perceptual asymmetries arise when verbal and nonverbal stimuli have the most direct access to the "target" hemisphere. In the present paradigm, the WS are presented at central fixation such that both hemispheres have immediate and direct access to the information conveyed by the WS. However, responses are not made to

the verbal and nonverbal WS, but to the "neutral" light stimulus that follows the WS. Thus, according to a pathway-transmission model, responses to a centrally presented neutral stimulus should be equally rapid for the left and right hand. This model does not in any straight forward manner take into account any material specific effects of the WS that precedes the RT stimulus. Consequently, the pathway-transmission model predicts that no RT asymmetries should occur with this paradigm, whereas as attentional model predicts that RT asymmetries should occur.

Specifically, the following predictions are made with respect to the hypothesis of material specific hemispheric activation. If verbal WS asymmetrically activate and prepare the left hemisphere for action, then RTs to a neutral stimulus will be faster for the right than left hand (Hypothesis I). Conversely, if nonverbal WS asymmetrically activate and prepare the right hemisphere for action, then RTs to a neutral stimulus will be faster for the left than right hand (Hypothesis II). Reaction times to a neutral stimulus will be faster with verbal than nonverbal WS when the right hand initiates a response (Hypothesis III). Finally, when responses are initiated by the left hand, RTs will be faster with nonverbal than verbal WS (Hypothesis IV).

If it is found that verbal and nonverbal WS produce RT asymmetries as predicted by the attentional hypothesis, this would suggest that the WS induced phasic asymmetric hemispheric activation. A critical question concerns the extent to which this asymmetric activation is temporally related to the WS and represents the second purpose of the present study. To address how long this asymmetric activation might persist, unwarned RT trials were randomly embedded among those trials that were immediately preceded by a verbal or nonverbal WS. If material specific hemispheric

activation is "stimulus bound" and "short lasting," then no RT asymmetries should occur for the unwarned trials embedded within the context of a verbal or nonverbal task. If, however, this asymmetric activation is "long lasting" and "tonic," then a similar pattern of RT asymmetries should occur for both the warned and unwarned trials. Kinsbourne's (1970a, 1975) cognitive set hypothesis would also predict that warned and unwarned trials within a session should exhibit similar patterns of RT asymmetries. The verbally/nonverbally warned trials would represent a "priming" task which should induce a verbal/nonverbal cognitive set.

It is possible that asymmetric hemispheric activation might persist throughout the session and even extend beyond the session itself. However, this "tonic" activation might attenuate immediately at cessation of the verbal and nonverbal RT tasks. To determine whether asymmetric hemispheric activation extends beyond the verbal and nonverbal sessions, blocks of unwarned RT trials were presented after the completion of the main verbal and nonverbal tasks. Again, similar patterns of RT asymmetries should occur for the post-session unwarned RT trials and the within-session warned trials, if asymmetric hemispheric activation is relatively long lasting. Within the framework of Kinsbourne's model, the main verbal and nonverbal RT tasks would constitute "priming" tasks. Kinsbourne would predict that the subsequent neutral task (i.e., the post-session trials) should be affected by the priming task and should exhibit RT asymmetries similar to those obtained on the "priming" task.

The third purpose of the present study concerns the distinction between involuntary selective attention and voluntary selective attention. It is not known, for example, whether asymmetric hemispheric activation can be induced by the presentation of any verbal or nonverbal stimulus

that does not require the S to make some discriminative judgement about stimulus categorization (attention) and response initiation (i)ntention). If a response-linked discriminative judgement is not necessary, then a simple RT paradigm should be sufficient for eliciting RT asymmetries. In this case, one could argue that asymmetric activation is characterized as a form of involuntary selective attention, in which the individual has little volitional control over a biologically innate activational response (i.e., OR) to verbal and nonverbal stimuli.

If, however, a response-linked decisional judgement is critical for inducing asymmetric hemispheric activation, then RT asymmetries should not occur with a simple RT paradigm. More complex RT tasks, in which the WS conveys discriminative information about what type response should be made to the RT stimulus, would be required before RT asymmetries could be obtained. In this case, one might argue that asymmetric hemispheric activation is characterized as a form of voluntary selective attention.

In order to distinguish between these two possibilities (i.e., voluntary versus involuntary), two experimental conditions were administered. For both conditions, verbal and nonverbal WS were used and manual responses were made to a neutral light stimulus. Similarly, both conditions contained embedded unwarned trials and were preceded and followed by blocks of unwarned Pre-session and Post-session trials. One condition, however, consisted of a simple warned RT paradigm, in which individuals were instructed to respond on every trial. The other condition was a "go-no go" RT paradigm, in which half the WS designated that a response should be made to the RT stimulus and the remaining WS indicated that no response should be made to the RT stimulus. Thus, the simple RT paradigm involved no discriminative decision concerning response selection, whereas a response-linked judgement was required in the "go-no go" condition.

## METHOD

### Subjects

The Ss were 32 right-handed college students, 16 females and 16 males, who ranged in age from 18 to 27 yrs (Mean = 21 yrs). All Ss were right-handed according to self-report and participated in this study as partial fulfillment of an undergraduate psychology course. Half the Ss (eight males and eight females) were randomly assigned to one experimental condition and the remaining Ss to a second experimental condition.

### Apparatus

In both experimental conditions, RTs were obtained to a binaurally presented tone of 250 ms. This tone was preceded at random intervals (500-1500 ms) by a visual WS of 500 ms. The WS were projected at central fixation via a tachistoscope (Polymetric, Model V-1459-B) onto a rear-view screen. At random intervals following the WS offset, a computer generated pure tone (500 Hz) was binaurally presented via Sennheiser stereo headphones at 60 db. To mask any distracting sounds, a low level of white noise (30 db) was continuously presented through the headphones, with the tone stimulus superimposed upon it. A BRS Foringer module was programmed to control stimulus durations, interstimulus intervals, and six sec intertrial intervals. Tone onset triggered a digital timer that was stopped when a manual response key was depressed by the index finger of either the right or left hand. The response key was placed on a table in front of S and located either 30 cm to the left or

to the right of the S's midline. Throughout the sessions, the Ss sat at a table 130 cm in front of the screen with their heads positioned in a commercial chin and forehead rest.

#### Warning Stimuli

Two classes of WS were used: verbal and nonverbal. The WS were presented in a blocked design so that only verbal or nonverbal WS were used during any one session. The verbal WS consisted of eight three-letter concrete nouns that were set in upper-case English letters. Each letter was vertically arrayed on a slide and appeared white against a darker grey-black background. The eight words were randomly assigned to one of two sets of stimuli. One set included the words BAG, DOT, PEN, and GUM (Set A), and the other set included FLY, DOG, BEE, and LEG (Set B).

The nonverbal WS consisted of two sets of four faces each. The faces were obtained from a college yearbook and selected in such a way as to minimize verbal coding (i.e., no glasses, no facial hair, hairlines obscured, all faces smiling and oriented in the same direction). One set consisted of four male faces (Set C) and the other set consisted of four female faces (Set D).

#### Go-No Go Condition

The 16 Ss assigned to this condition participated in four separate testing sessions given one week apart and lasting approximately one hr each. Two of the sessions were "verbal" in that words were used as WS. In one verbal session, the words from Set A were used and in the other verbal session the words from Set B were used as WS. The remaining two sessions were "nonverbal" and the faces from Set C or Set D were used as WS. Within each session, the WS were randomized and occurred equally often across trials. Half the Ss received the two verbal sessions first and half the two nonverbal sessions first.

### Go and Tonic Trials

In each session, two of the four stimuli within each WS set were assigned as "go" stimuli and two as "no go" stimuli. The "go" WS signalled that the S should depress the response key at tone onset, and the "no go" WS signalled that no response should be made to tone onset. The stimulus pairs, assigned as "go" or "no go" WS, were counterbalanced across Ss and conditions.

At the beginning of each session, the Ss were trained to discriminate between the "go" and "no go" WS. The designated WS were shown for two min to the Ss who were instructed to remember them. This was followed by a block of 64 practice trials in which the Ss were given feedback about their correct and incorrect responses. Incorrect responses were of two types including: (a) those in which no response was made to the RT stimulus when it was preceded by a "go" WS (i.e., omissions); and (b) those in which responses were made to the RT stimulus when it was preceded by a "no go" WS (i.e., commissions).

The practice trials were followed by two blocks of 64 experimental trials, with a five min rest interval between the two blocks. Within each block of trials, there were 26 warned "go" trials and 26 warned "no go" trials. For the remaining 12 trials in each block, no WS preceded the tone. These unwarned trials ("tonic" RTs) were randomly embedded among the warned trials, and Ss were instructed to respond to these. Thus, Ss responded to the RT stimulus when it was preceded by either the "go" WS (Go RT) or no WS (Tonic RT).

Two sessions were completed by the right hand (one verbal and one nonverbal) and two sessions by the left hand. Each S, therefore, received all combinations of Hand X Type WS (i.e., Right hand-Verbal WS,

Left hand-Verbal WS, Right hand-Face WS, Left hand-Face WS). Hand order was counterbalanced across sessions and Ss (RLLR or LRRL).

### Pre-Post Trials

Prior to the beginning of the verbal and nonverbal RT tasks, each S performed 20 simple RTs to a binaurally presented tone. These trials were unwarned and had intertrial intervals ranging from five to 10 sec. Half the trials were completed by the right hand and half by the left hand (RLLR or LRRL). At the end of each verbal and nonverbal session, this identical procedure was repeated. Thus, both "Pre" and "Post" simple RTs were obtained for each hand during each verbal and nonverbal session.

### Simple RT Condition

The 16 Ss assigned to this condition participated in two separate testing sessions (one verbal and one nonverbal) given one week apart and lasting approximately one hr each. In the verbal session, either the words from Set A or Set B were used as WS and in the nonverbal session, faces from Set C or Set D were used as WS. The WS sets were counterbalanced across Ss. Within each session, the WS were randomized, but occurred equally often across trials. Half the Ss received the verbal session first and half the nonverbal session first.

### Go and Tonic Trials

Unlike the Go-No Go Condition, Ss assigned to the simple RT task were instructed to respond on every trial. This eliminated any differential decision as to respond, based on the information conveyed by the WS. Consequently, every trial was a "go" trial.

Each session consisted of 64 practice trials that were followed by two blocks of 64 experimental trials. A five min rest interval occurred

between the two blocks of trials, and hand order was counterbalanced across blocks (RL or LR). Within each block, 12 unwarned trials were randomly embedded among the 52 warned trials. The Ss were instructed to depress the response key at tone onset, whether the trials were warned or unwarned ("tonic" RT).

Following the completion of the verbal or nonverbal trials, the Ss were shown an array of 16 words/faces arranged on a 20.3 X 27.9 cm piece of white paper. The Ss were asked to select those items which had been used as WS during that particular session. The number of correct choices was recorded. This was done in order to determine whether the Ss had differentiated among the WS used during a session.

#### Pre-Post Trials

As described in the Go-No Go Condition, blocks of simple unwarned RT trials were also administered prior to and following each session. Each S was given 20 simple RT trials prior to the session and again after the session was completed. These trials were unwarned, and half were completed by the left hand and half by the right hand (RLLR or LRRL). Thus, both "Pre" and "Post" simple RTs were obtained for each hand during each session.

#### Analyses

The RTs from each experimental condition (Go-No Go and Simple) were analyzed in terms of mean RT in ms. Reaction times that exceeded 1000 ms were defined as omissions and RTs shorter than 50 ms were defined as anticipations. In the Simple RT Condition, the mean number of omissions and anticipations was computed. In the Go-No Go Condition, the mean number of anticipations, omissions, and commissions was computed.

Within each condition, the three dependent variables of major interest were: (a) RTG ("go" RTs to the tone that was preceded by the WS); (b) RTT (unwarned "tonic" RT trials that were embedded among the warned RTG trials); and (c) Pre-Post RTs (unwarned trials prior to and following the verbal or nonverbal RT tasks).

Since it was felt that intrinsic differences in motor agility between the left and right hands might disproportionately affect the direction of RTs, baseline RTs were determined for each hand. This was done by computing the RT means of each hand from the unwarned Pre-session trials. For example, in the verbal session where right hand responses were measured, the baseline RT was computed from the mean of the 10 Pre-session trials. These baseline RTs were used as covariate values in the subsequent analyses.

For each experimental condition, two separate analyses of covariance were performed for the two dependent variables, RTG and RTT. Within-S factors were Hand (Right versus Left), Type WS (Words versus Faces), Block (1 versus 2), and Covariate. The Pre-Post RTs were analyzed using an analysis of variance with Hand (Right versus Left), Time (Pre versus Post), and Type Intervening Task (Verbal versus Nonverbal) as within-S factors.

## RESULTS

The results are presented in two sections. The first section deals with the RTs obtained in the Go-No Go Condition and generally addresses the hypothesis that material specific hemispheric activation represents a form of voluntary selective attention-intention. The second deals with RTs obtained from the Simple RT Condition and addresses the hypothesis that material specific hemispheric activation can be characterized as a form of involuntary selective attention.

If the predicted RT asymmetries are found only in the Go-No Go Condition, this would suggest that material dependent activation is voluntary. If, however, the predicted RT asymmetries are also obtained in the Simple RT Condition, this would indicate that material specific hemispheric activation is involuntary. Since the distinction between these two possibilities can be most easily drawn by analyzing the two RT conditions separately, the data are presented in this way.

The overall mean RTs from the Go-No Go and Simple RT tasks (collapsed across Hand, Type WS, and Block) are presented in Table 9. As can be seen, the RTs from the Go-No Go Condition are approximately 10 ms faster than those obtained from the Simple RT task. More importantly, however, is that the RTs from the Go-No Go Condition are much more variable. The source of this variability is unclear and possibly reflects a number of factors including S sampling differences, paradigm differences (four sessions versus two sessions), or task differences directly related to the different cognitive requirements of a go-no go versus a

simple RT procedure. It was this differing variability that further prompted separate analyses of the two experimental tasks.

TABLE 9  
MEAN REACTION TIMES IN THE GO-NO GO AND  
SIMPLE RT TASKS

	Go-No Go Condition	Simple RT Condition
M*	229.6 ms	238.9 ms
S.D.	56.6 ms	28.9 ms

\*Means are adjusted for the covariate.

#### Analyses of the Go-No Go Condition

The overall error rate (anticipations + omissions + commissions/total number of trials) was 3.8%. Consequently, the RT means of the Hand X Type WS X Block matrix for each S are based on approximately 96% of the administered trials. Three separate analyses (RTG, RTT, and Pre-Post RTs) were performed and the results of each are discussed separately below.

#### Go RTs (RTG)

The results of the analysis of covariance of the "go" RTs are presented in Table 10. A significant covariate effect was found ( $F_{1,104} = 10.7$ ,  $p < .01$ ), which justifies the use of the covariance procedure. The mean covariate values for each session are presented in Table 11.

The Hand X Type WS interaction was also significant ( $F_{1,104} = 7.89$ ,  $p < .01$ ) and is depicted in Figure 1. Post hoc comparisons, using Duncan's procedure, indicated that: (a) RTs by the right hand were significantly faster when the WS was a word, rather than a face (Word = 202.8 ms, Face = 240.5 ms,  $p < .05$ ); (b) With word WS, right hand RTs were faster

TABLE 10  
SUMMARY OF ANALYSIS OF COVARIANCE  
OF THE MEAN "GO" REACTION TIMES IN THE GO-NO GO CONDITION

Source	df	SS	F	p
Covariate	1	34239.61	10.70	.0015*
Hand	1	7759.51	2.47	NS**
Warning Stimulus (WS)	1	2682.19	.83	NS
Block	1	2329.80	.72	NS
Hand X WS	1	25253.11	7.89	.0059*
Hand X Block	1	2350.20	.73	NS
WS X Block	1	4793.73	1.49	NS
WS X Block X Hand	1	712.92	.22	NS
Within-Subject	15	342581.79	7.13	
Error	104	332749.04		
TOTAL	127	845668.92		

\* $p < .01$

\*\*Not significant

TABLE 11  
MEAN COVARIATE VALUES OF THE  
RIGHT AND LEFT HANDS FOR VERBAL AND NONVERBAL SESSIONS  
IN THE GO-NO GO CONDITION

	Verbal Sessions	Nonverbal Sessions
Right Hand	225.9 ms	215.9 ms
Left Hand	235.1 ms	236.4 ms

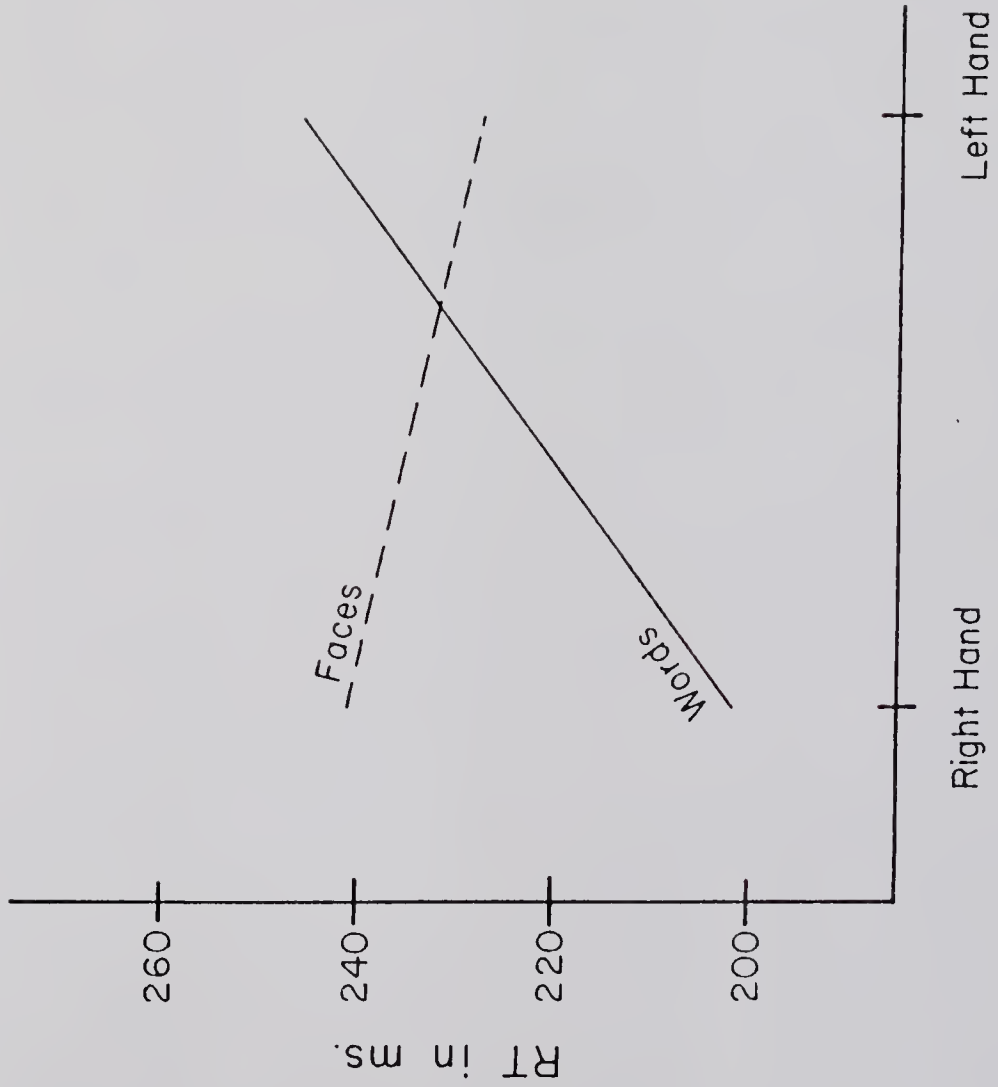


FIGURE 1. MEAN "GO" REACTION TIMES OF RIGHT AND LEFT HANDS WITH EITHER WORD OR FACE WARNING STIMULI IN THE GO-NO GO CONDITION

than left hand RTs (Right = 202.8 ms, Left = 246.0 ms,  $p < .05$ ); and (c) For the left hand, there were no RT differences between word and face WS (Word = 246.1 ms, Face = 227.0 ms). Similarly, there were no between-hand differences in RT when faces were used as WS (Right = 240.5 ms, Left = 227.0 ms).

The means and Duncan's post hoc test of significance for the Hand X Type WS interaction are presented in Tables 12 and 13. All remaining effects and interactions were nonsignificant.

#### Tonic RTs (RTT)

The results of the analysis of covariance for the RTT data are presented in Table 14. A significant covariate effect was found ( $F_{1,104} = 8.01$ ,  $p < .01$ ). The mean covariate values for each session are identical to those used in the RTG analysis and are again found in Table 11.

All remaining effects and interactions were nonsignificant. The Hand X Type WS interaction approached, but did not reach significance ( $F_{1,104} = 3.12$ ,  $p = .08$ ; See Figure 2). The trend of this interaction, which was in the same direction as that found with the RTG data, lends some support to the hypothesis of a "tonic" carry over effect from the warned to the unwarned trials. The means of this interaction are presented in Table 15.

#### Pre-Post RTs

The results of the analysis of variance of the Pre-Post data are presented in Table 16. Significant main effects were found for both Time ( $F_{1,233} = 6.26$ ,  $p < .01$ ) and Type Intervening Task ( $F_{1,233} = 5.89$ ,  $p < .01$ ). The means for these effects are presented in Tables 17 and 18. Reaction times prior to the intervening task (Pre = 227.0 ms) were faster than those following the intervening task (Post = 234.6 ms), and

TABLE 12

MEAN REACTION TIMES OF RIGHT AND LEFT HANDS  
WITH WORD OR FACE WARNING STIMULI IN THE GO-NO GO CONDITION

Right Hand	202.9 ms* (45.4 ms)**	240.5 ms (100.4 ms)
Left Hand	246.1 ms (73.1 ms)	221.8 ms (89.5 ms)

\*All means are adjusted for the covariates.

\*\*Standard deviations are in parentheses.

TABLE 13

DUNCAN'S POST HOC COMPARISONS OF MEAN REACTION TIMES  
OF RIGHT AND LEFT HANDS WITH WORD OR FACE WARNING STIMULI

Ordered Means	Mean Differences			
	1	2	3	4
202.9 ms	-	24.9	37.6*	43.2*
227.8 ms		-	12.7	18.3
240.5 ms			-	5.6
246.1 ms				-

\* $p < .05$  (Two-tailed test of significance)

TABLE 14

SUMMARY OF ANALYSIS OF COVARIANCE  
OF THE MEAN "TONIC" REACTION TIMES IN THE GO-NO GO CONDITION

Source	df	SS	F	p
Covariate	1	77886.19	8.01	.0056*
Hand	1	6.55	.00	NS**
Warning Stimulus (WS)	1	820.12	.08	NS
Block	1	9449.98	.97	NS
Hand X WS	1	30338.67	3.12	.0800
Hand X Block	1	11279.09	1.16	NS
WS X Block	1	1064.16	.11	NS
WS X Block X Hand	1	1512.79	.16	NS
Within-Subject	15	1073449.08	7.36	
Error	104	1010943.11		
TOTAL	127	2387710.73		

\* $p < .01$

\*\*Not significant

TABLE 15

MEAN REACTION TIMES OF RIGHT AND LEFT HANDS  
TO AN UNWARNED TONE EMBEDDED AMONG VERBAL OR NONVERBAL WARNED  
TRIALS IN THE GO-NO GO CONDITION

	Verbal Trials	Nonverbal Trials
Right Hand	278.3 ms* (120.6 ms)**	314.5 ms (140.1 ms)
Left Hand	309.7 ms (135.7 ms)	283.9 ms (144.2 ms)

\*All means are adjusted for the covariates.

\*\*Standard deviations are in parentheses.

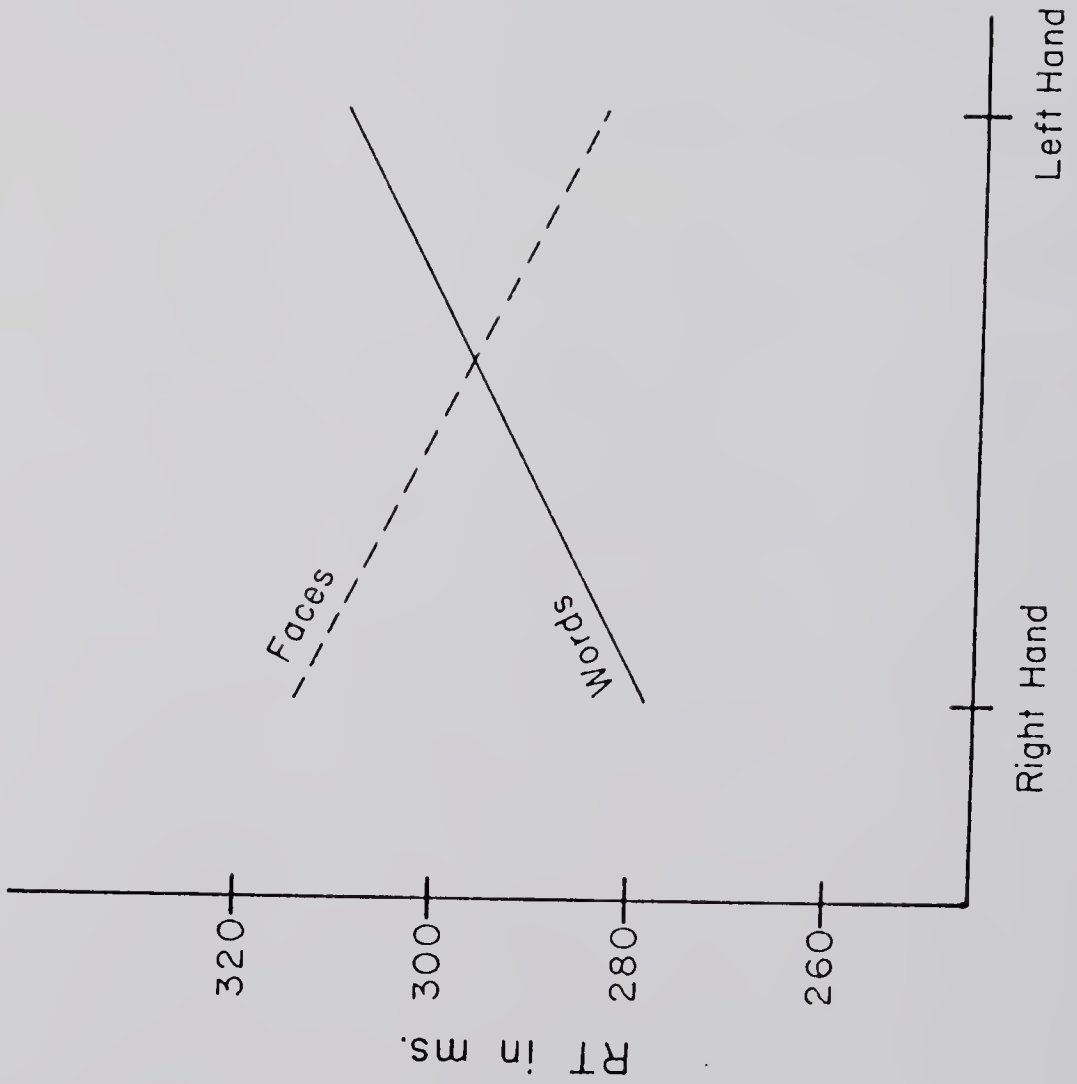


FIGURE 2. MEAN "TONIC" REACTION TIMES OF RIGHT AND LEFT HANDS TO AN UNWARNED TONE EMBEDDED AMONG VERBAL OR NONVERBAL WARNED TRIALS IN THE GO NO GO CONDITION

TABLE 16  
SUMMARY OF ANALYSIS OF VARIANCE  
OF THE MEAN "PRE-POST" REACTION TIMES IN THE  
GO-NO GO CONDITION

SOURCE	df	SS	F	p
Hand	1	4.78	.00	NS*
Time	1	370957.12	6.26	.013**
Intervening Task (IT)	1	349059.41	5.89	.016**
Hand X Time	1	70523.44	1.19	NS
Hand X IT	1	926.44	.02	NS
Time X IT	1	2306032.06	38.93	.001**
Hand X Time X IT	1	50934.84	.86	NS
Within-Subject	15	2104569.21	23.69	
Error	233	13800542.56		
TOTAL	255	37994849.89		

\*Not significant

\*\*p < .05

TABLE 17

MEAN "PRE-POST" REACTION TIMES  
PRIOR TO AND FOLLOWING THE MAIN TASK IN THE GO-NO GO CONDITION

	Pre-Session	Post-Session
M	227.0 ms	234.6 ms
S.D.	35.2 ms	41.0 ms

TABLE 18

MEAN "PRE-POST" REACTION TIMES  
WITH EITHER VERBAL OR NONVERBAL INTERVENING TASK  
IN THE GO-NO GO CONDITION

	Verbal	Nonverbal
M	234.5 ms	227.2 ms
S.D.	40.1 ms	36.9 ms

overall RTs performed with the nonverbal intervening task (Mean = 227.1 ms) were faster than those performed with the verbal intervening task (Mean = 234.5 ms).

The Time X Type Intervening Task interaction was also significant ( $F_{1,233} = 38.9, p < .01$ ) and is depicted in Figure 3. Post hoc comparisons (Duncan's procedure) revealed that: (a) When the intervening task was nonverbal, there were no RT differences between Pre- and Post-trials (Pre = 232.8 ms, Post = 221.4 ms); (b) In contrast, RTs following the verbal task were significantly slower than those preceding the verbal task (Pre = 221.2 ms, Post = 247.8 ms,  $p < .05$ ); (c) During the Post-trials, RTs following the nonverbal task were significantly faster than those following the verbal task (Nonverbal = 221.4 ms, Verbal = 247.8 ms,  $p < .05$ ); and (d) During the Pre-trials, there were no differences in RTs prior to the verbal task, when compared to those prior to the nonverbal task (Verbal 221.2 ms, Nonverbal 232.8 ms). The means of this interaction and Duncan's post hoc test of significance are presented in Tables 19 and 20.

#### Anticipations, Omissions, and Commissions

The mean numbers of anticipations, omissions, and commissions for each S were 3.0, 7.0, and 5.9, respectively. The frequency of each of these error types across each Hand X Type WS condition are presented in Tables 21, 22, and 23. Since the occurrence of error types across the Hand X Type WS categories was not independent for each S, one basic assumption underlying the Chi-Square test was violated. Consequently, the Cochran Q-test (Seigle, 1956) for related dichotomized data was used.

Results of three separate Cochran Q-tests revealed that: (a) the frequency of anticipations was different across the Hand X Type WS

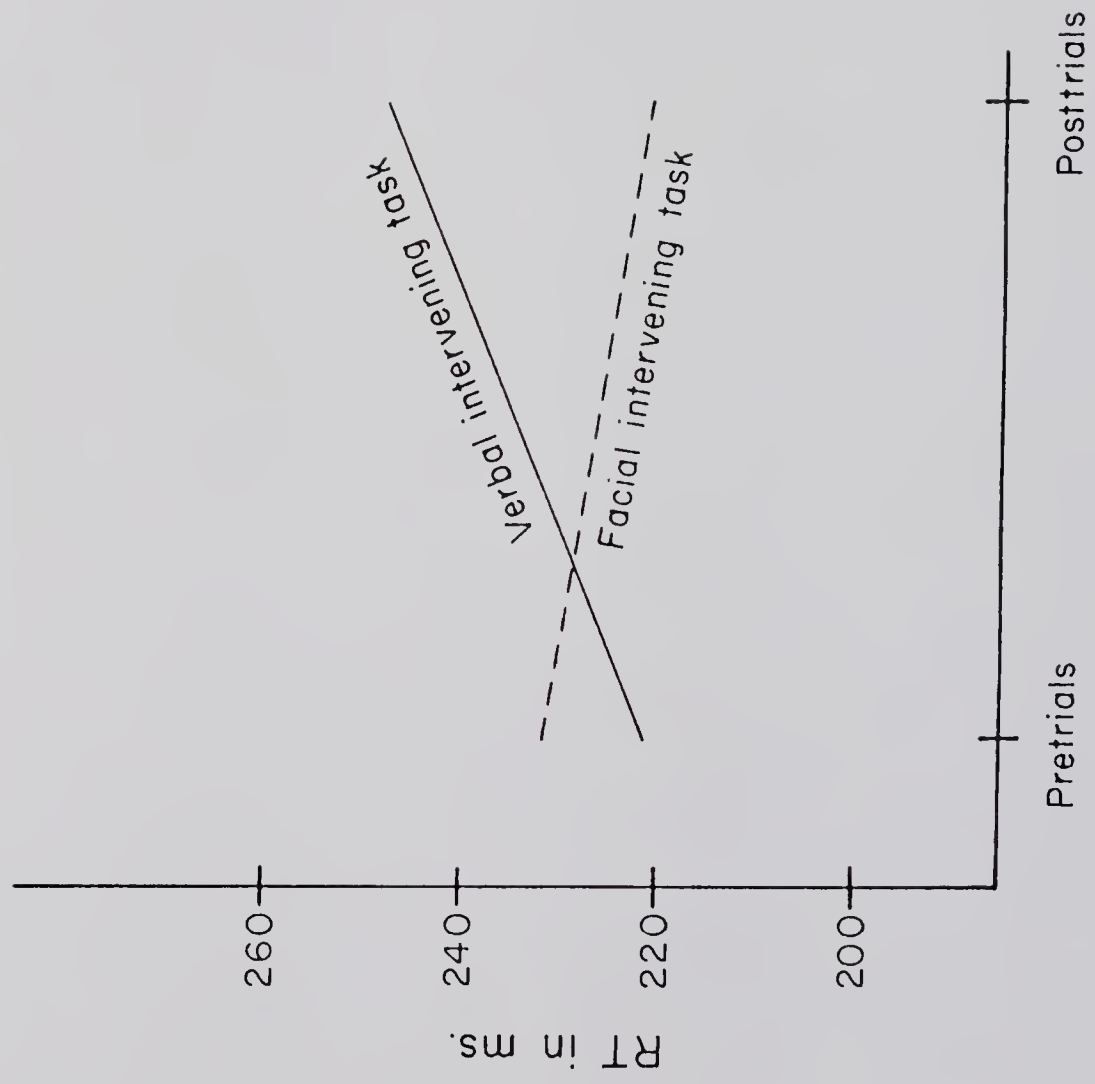


FIGURE 3. MEAN "PRE-POST" REACTION TIMES PRIOR TO AND FOLLOWING A VERBAL OR NONVERBAL INTERVENING TASK IN THE GO-NO GO CONDITION

TABLE 19

MEAN REACTION TIMES PRIOR TO AND FOLLOWING  
EITHER A VERBAL OR NONVERBAL INTERVENING TASK IN THE GO-NO GO CONDITION

	Pre-Session	Post-Session
Verbal Intervening Task	221.2 ms (30.8 ms)	247.8 ms (44.1 ms)
Nonverbal Intervening Task	232.8 ms (39.5 ms)	221.4 ms (33.6 ms)

\*Standard deviations are in parentheses.

TABLE 20

DUNCAN'S POST HOC COMPARISONS OF MEAN REACTION TIMES  
PRIOR TO AND FOLLOWING A VERBAL OR NONVERBAL INTERVENING TASK  
IN THE GO-NO GO CONDITION

Ordered Means	1	2	3	4
221.2 ms	-	.2	11.6	26.6*
221.4 ms		-	11.4	20.4*
232.8 ms			-	15.0
247.8 ms				-

\* $p < .05$  (Two-tailed test of significance)

TABLE 21

FREQUENCY OF ANTICIPATIONS  
BY RIGHT AND LEFT HANDS WITH VERBAL AND NONVERBAL  
WARNING STIMULI IN THE GO-NO GO CONDITION

	Verbal	Nonverbal
Right Hand	24	11
Left Hand	5	9

TABLE 22

FREQUENCY OF OMISSIONS  
BY RIGHT AND LEFT HANDS WITH VERBAL AND NONVERBAL  
WARNING STIMULI IN THE GO-NO GO CONDITION

	Verbal	Nonverbal
Right Hand	14	38
Left Hand	11	49

TABLE 23

FREQUENCY OF COMMISSIONS  
BY RIGHT AND LEFT HANDS WITH VERBAL AND NONVERBAL  
WARNING STIMULI IN THE GO-NO GO CONDITION

	Verbal	Nonverbal
Right Hand	17	30
Left Hand	12	34

categories ( $Q = 14.7, p < .01$ ). With verbal WS, more anticipations were made by the right than left hand. However, there were no between-hand differences with nonverbal WS; (b) The frequency of omissions differed across the Hand X Type WS categories ( $Q = 16.7, p < .001$ ). More omissions were made with nonverbal than verbal WS; and (c) The frequency of commissions also differed across the Hand X Type WS categories ( $Q = 15.2, p < .001$ ). More commissions were made with nonverbal than verbal WS.

### Analyses of the Simple RT Condition

The overall error rate (anticipations + omissions/total number of trials) was .7%. Consequently, the RT means of the Hand X Type WS X Block matrix for each S are based on approximately 99% of the administered trials.

### Go RTs (RTG)

The results of the analysis of covariance of the "go" RTs are presented in Table 24. A significant main effect for Type WS was found ( $F_{1,104} = 12.5, p < .05$ ). Reaction times with face WS were faster than those with word WS (Face = 229.3 ms, Word = 247.8 ms; See Table 25). All remaining effects and interactions were nonsignificant.

Since it was possible that the Ss in the Simple RT Condition may have responded to the word/face WS in a nondiscriminatory manner, this was tested by determining the Ss' accuracy in correctly identifying, from an array of 16 faces/words, the particular WS that had been used during a session. At the completion of the verbal session, all 16 Ss were 100% accurate in identifying the four word WS. Following the nonverbal session, 13 Ss were 100% accurate and three Ss were 75% accurate in identifying the target face WS.

TABLE 24  
SUMMARY OF ANALYSIS OF COVARIANCE  
OF THE MEAN "GO" REACTION TIMES IN THE SIMPLE RT CONDITION

Source	df	SS	F	p
Covariate	1	523.35	.63	NS*
Hand	1	339.39	.40	NS
Warning Stimulus (WS)	1	10491.43	12.51	.0001**
Block	1	38.32	.61	NS
Hand X WS	1	510.21	.05	NS
Hand X Block	1	788.72	.94	NS
WS X Block	1	304.44	.36	NS
Hand X Block X WS	1	49.05	.06	NS
Within-Subject	15	150028.95	11.63	
Error	104	87156.74		
TOTAL	127	538447.25		

\*Not significant

\*\*p < .01

TABLE 25  
MEAN "GO" REACTION TIMES  
WITH WORD OR FACE WARNING STIMULI  
IN THE SIMPLE RT CONDITION

	Verbal	Nonverbal
M*	247.4 ms	229.3 ms
S.D.	62.8 ms	53.3 ms

\*Means are adjusted for the covariate

### Tonic RTs (RTT)

The results of the analysis of covariance of the RTT data are presented in Table 26. There were no significant main effects or interactions. The Condition effect approached, but did not reach significance ( $F_{1,104} = 3.3, p = .07$ ). Thus, there was a trend for the unwarned trials embedded within the nonverbal task to be faster than those trials embedded within the verbal task (Nonverbal = 301.9 ms, Verbal = 334.9 ms, See Table 27).

### Pre-Post RTs

The results of the analysis of variance of the Pre-Post RTs are presented in Table 28. A significant Hand X Time interaction was found ( $F_{1,105} = 7.3, p < .01$ ) and is depicted in Figure 4. Post hoc comparisons, using Duncan's procedure, revealed that: (a) RTs by the right hand remained unchanged across Pre- and Post-trials (Pre = 245.5 ms, Post = 252.4 ms), regardless of the type of intervening task; (b) In contrast, left hand RTs were significantly faster during the Post-trials when compared to left hand RTs during the Pre-trials (Post = 234.9 ms, Pre = 262.4 ms,  $p < .05$ ); (c) During the Pre-trials, right hand RTs were faster than left hand RTs (Right = 245.3 ms, Left = 261.4 ms,  $p < .05$ ); and (d) Conversely, left hand RTs were faster than right hand RTs during the Post-trials (Left = 234.9 ms, Right = 252.4 ms,  $p < .05$ ). The means of this interaction and post hoc tests of significance are presented in Tables 29 and 30.

### Anticipations and Omissions

The mean number of anticipations and omissions for each S were 2.0 and .5, respectively. The frequency of each of these error types across each Hand X Type WS category are presented in Tables 31 and 32. The

TABLE 26

SUMMARY OF ANALYSIS OF COVARIANCE  
OF THE MEAN "TONIC" REACTION TIMES IN THE SIMPLE RT CONDITION

Source	df	SS	F	p
Covariate	1	19545.70	1.83	NS*
Hand	1	1663.13	.15	NS
Warning Stimulus (WS)	1	34774.13	3.25	.070**
Block	1	7791.70	.73	NS
Hand X WS	1	9800.63	.92	NS
WS X Block	1	812.95	.08	NS
Hand X Block	1	1826.25	.17	NS
Hand X WS X Block	1	8843.80	.82	NS
Within-Subject	15	410094.70	2.56	
Error	104	1111302.45		
TOTAL	127	2566776.66		

\*Not significant

\*\*p < .10

TABLE 27

MEAN "TONIC" REACTION TIMES  
EMBEDDED WITHIN VERBAL OR NONVERBAL TRIALS  
IN THE SIMPLE RT CONDITION

	Verbal	Nonverbal
M*	334.9 ms	301.9 ms
S.D.	154.4 ms	127.7 ms

\*Means are adjusted for the covariates.

TABLE 28  
SUMMARY OF ANALYSIS OF VARIANCE  
OF THE MEAN "PRE-POST" REACTION TIMES IN THE  
SIMPLE RT CONDITION

SOURCE	df	SS	F	p
Hand	1	12.50	.01	NS*
Time	1	2939.53	2.25	NS
Intervening Task (IT)	1	.32	.00	NS
Hand X Time	1	9058.58	7.25	.0082**
Hand X IT	1	.19	.00	NS
Time X IT	1	95.91	.08	NS
Hand X IT X Time	1	550.29	.44	NS
Within-Subject	15	181260.65	9.68	
Error	105	131129.97		
TOTAL	127	325047.94		

\*Not significant

\*\* $p < .01$

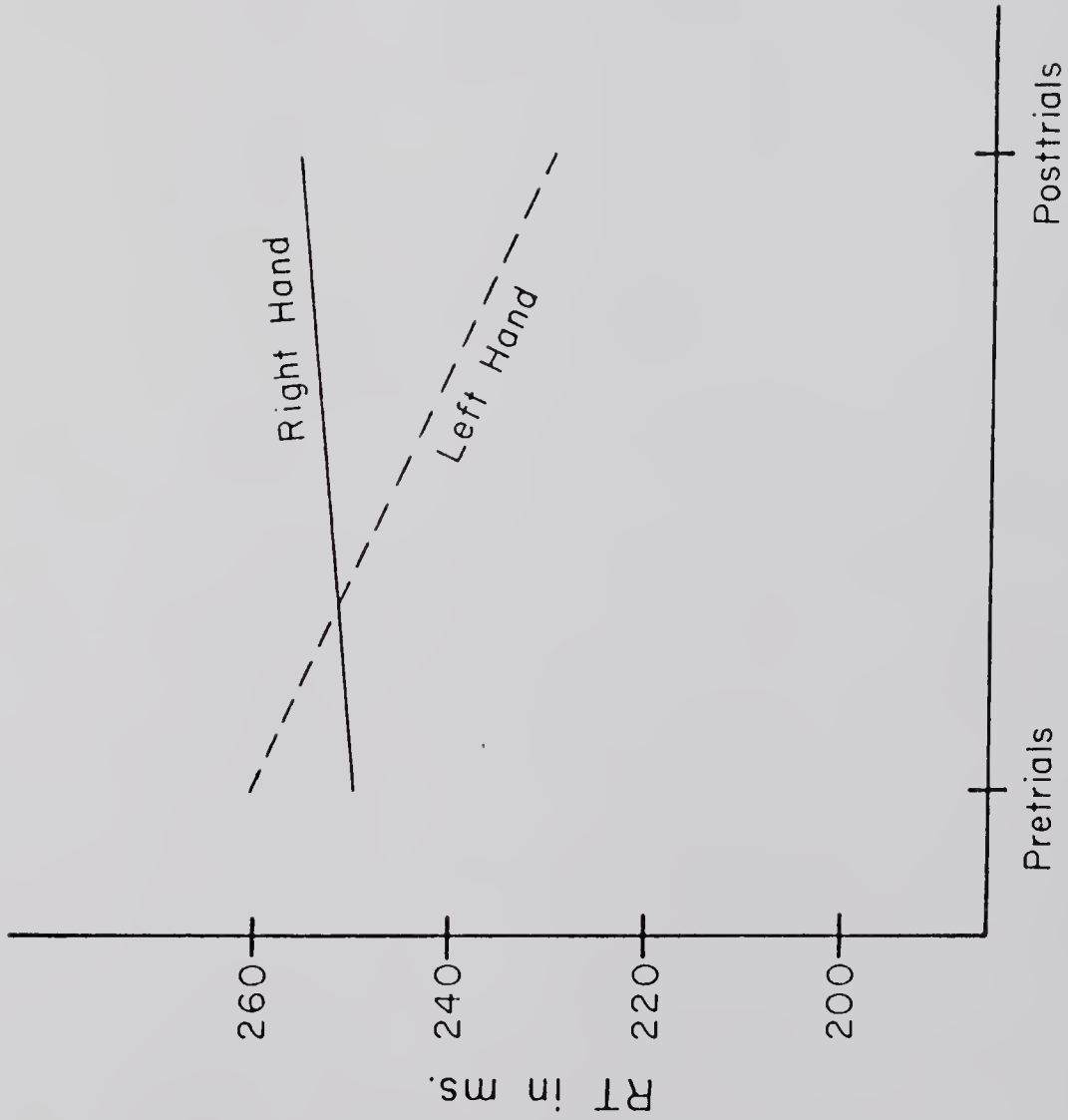


FIGURE 4. MEAN "PRE-POST" REACTION TIMES PRIOR TO AND FOLLOWING AN INTERVENING TASK IN THE SIMPLE REACTION TIME CONDITION

TABLE 29

MEAN "PRE-POST" REACTION TIMES  
BY RIGHT AND LEFT HANDS PRIOR TO AND FOLLOWING AN INTERVENING TASK  
IN THE SIMPLE RT CONDITION

	Pre-Session	Post-Session
Right Hand	245.2 ms (56.2 ms)*	252.4 ms (28.3 ms)
Left Hand	261.4 ms (71.3 ms)	234.9 ms (32.3 ms)

\*Standard deviations are in parentheses.

TABLE 30

DUNCAN'S POST HOC COMPARISONS OF MEAN REACTION TIMES  
BY RIGHT AND LEFT HANDS PRIOR TO AND FOLLOWING AN INTERVENING TASK  
IN THE SIMPLE RT CONDITION

Ordered Means	1	2	3	4
234.9 ms	-	10.3	17.5*	26.5*
245.2 ms		-	7.2	26.2*
252.4 ms			-	9.0
261.4 ms				-

\* $p < .05$  (Two-tailed test of significance)

TABLE 31

FREQUENCY OF ANTICIPATIONS  
BY RIGHT AND LEFT HANDS WITH VERBAL AND NONVERBAL  
WARNING STIMULI IN THE SIMPLE RT CONDITION

	Verbal	Nonverbal
Right Hand	8	5
Left Hand	3	1

TABLE 32

FREQUENCY OF OMISSIONS  
BY RIGHT AND LEFT HANDS WITH VERBAL AND NONVERBAL  
WARNING STIMULI IN THE SIMPLE RT CONDITION

	Verbal	Nonverbal
Right Hand	8	5
Left Hand	3	1

results of two separate Cochran Q-tests revealed that: (a) The frequency of anticipations differed across the Hand X Type WS categories ( $Q = 7.4$ ,  $p < .05$ ); and (b) The frequency of omissions did not differ across each Hand X Type WS category ( $Q = 4.0$ ,  $p > .05$ ).

## DISCUSSION

The present results lend partial support to the hypothesis that verbal and nonverbal stimuli selectively activate and prepare the hemispheres for action. Furthermore, this asymmetric activation appears to occur only when the verbal and nonverbal WS convey discriminative information about what type of response should be made. The latter is based on findings that no material specific asymmetries in RT occurred between the hands when the WS merely forewarned (Simple RT Condition), as opposed to both forewarned and dictated whether or not a response should be made (Go-No Go Condition). This suggests that a response-linked decisional process is necessary for inducing RT asymmetries and that material specific hemispheric activation can be characterized as a form of voluntary selective attention.

The different findings for the Simple and Go-No Go tasks could possibly reflect subject sample differences. Since the Ss were randomly assigned to these two tasks, there is no a priori reason to assume that there were sampling differences. However, this is a possibility. Another explanation for the lack of RT asymmetries in the Simple RT task is that the Ss were not attentive to subtle differences in stimulus features among the WS. The Ss possibly treated the verbal/nonverbal WS as "neutral" light flashes, without specifically encoding them as particular words/faces. Inattentiveness to the WS seems unlikely, however, since the Ss were accurate in identifying the specific WS that had been used during a particular session.

A more probable explanation for the lack of asymmetries in the Simple RT task is that the WS were not linked to a differential decision as to the type of response that should be made. The implication, of course, is that an important and perhaps necessary component of material specific RT asymmetries is selective intention. Data directly bearing on the importance of response-linked decisional processes are drawn from the laterality literature. Most, and perhaps all, laterality investigators who have used RT as the dependent variable, have employed either choice or go-no go procedures (Davis & Schmit, 1971; Geffen, Bradshaw, & Nettleton, 1972; Geffen, Bradshaw, & Wallace, 1971; Levy & Bowers, 1974; Moscovitch, 1973; Rizzolatti, Berlucchi, & Umiltà, 1971; Springer, 1971; Umiltà, Frost, & Hymen, 1972). Geffen and coworkers (1971, 1972) obtained RTs to verbal and nonverbal visual stimuli presented to the left and right VHF. With a choice RT task, words were responded to more quickly in the RVF than LVF, and vice versa for face stimuli. However, no RT asymmetries were found when a simple RT paradigm was used.

Thus, support for the material specific hemispheric activation hypothesis occurred only when the WS dictated differential responses, and furthermore was confined entirely to findings with the verbal WS. Right hand RTs were faster than left hand RTs with verbal WS (Hypothesis I), suggesting that verbal stimuli selectively activate the left hemisphere. This activation appears to "prepare the left hemisphere for action" since faster RTs were obtained for verbal than nonverbal WS when the right hand was used (Hypothesis III). No between-hand asymmetries were found with the nonverbal WS (Hypothesis II), suggesting that both hemispheres were activated by the nonverbal WS. Furthermore, no verbal-nonverbal asymmetries were observed when the left hand initiated a response (Hypothesis IV).

Several possibilities might account for the unpredicted results with the nonverbal WS. First, the face WS may have been bilaterally processed. Although an attempt was made to reduce the number of taggable features, the left hemisphere may have encoded the faces in terms of salient features that could be verbally described (i.e., dark, bushy eyebrows) or it may have encoded a name (i.e., John) that was associated with a group of these features. The right hemisphere, on the other hand, may have encoded the face as a visual configuration/gestalt or transformed it so that it matched an ideal representation of the face in memory.

There is some indication that this type process occurs in reading letters (Davis & Schmit, 1973; Klatzky, 1972). Starting from a common visual trace, each hemisphere appears to process letters differently, but in parallel with each other: the right hemisphere attends to visual features and the left hemisphere to linguistic ones. The underlying principle stems from the "strategy-specific" model of laterality. Namely, both hemispheres can participate concurrently and independently in the processing of two disparate components of the same stimulus. In particular, each hemisphere can process the component parts of a complex stimulus for which its descriptive systems are specifically equipped.

Despite the possible involvement of left hemisphere mechanisms in processing faces, substantial evidence exists from both normal (Bradshaw & Wallace, 1971; Geffen et al., 1971; Hilliard, 1973; Klein et al., 1976; Moscovitch, Scullion, & Christie, 1976; Rizzolatti, et al., 1971) and clinical populations (DeRenzi, Faglioni, & Spinnler, 1968; Milner, 1968; Warrington & James, 1967) that the right hemisphere is more adept at processing these stimuli. There are, however, several critical methodological considerations which contribute to or interfere with clearcut

perceptual asymmetries for faces in laterality paradigms: (a) the necessity of a memory component; (b) the time interval between a target (i.e., to be remembered) and test face; and (c) the amount of time exposure to the target and test faces.

Typically, most researchers concerned with the hemispheric processing of faces have incorporated either a short-term or long-term memory requirement into their experimental paradigms. Moscovitch, Scullion, and Christie (1976) found that when the memory requirement was removed, perceptual asymmetries for faces disappeared. In this study, both members of a pair of faces were presented simultaneously to either the left or the right VHF, and Ss judged whether the faces were same or different. No VHF advantages were found. Only when the faces were compared to those represented in memory did a consistent LVF superiority emerge.

These findings with normal individuals are paralleled by findings from the clinical literature. Impaired memory for faces is associated with lesions of the right hemisphere (Milner, 1968), and impaired recognition of faces, i.e., prosopagnosia, is associated with bilateral posterior hemispheric disease.

A second methodologic variable affecting perceptual asymmetries for faces is the time interval between the target and test face. Moscovitch et al. (1976) reported that the interval between presentation of an initial target face and a subsequent comparison face is critical for producing LVF superiorities. With interstimulus intervals less than 100 ms, both hemispheres were equally adept at processing a "short-lived visual trace" of the target face. Beyond that time, the right hemisphere appeared to have privileged access to a more "permanent memory representation" of the target face, in that a robust LVF advantage emerged.

A third methodologic factor, most relevant to the present study, concerns the duration of initial time exposure to the target and test faces. With increasing time exposure, there is increased probability that the face will be verbally coded. The present paradigm, in which Ss initially perused the target face for several min, differs considerably from VHF studies in which the target face is presented on the order of 60-300 ms. Similarly, the test face in the present study (i.e., the WS) was presented for 500 ms, which greatly exceeds the usual 50-75 ms exposure of test faces in VHF paradigms.

Consequently, one might argue that asymmetries with nonverbal stimuli, including faces, are more evasive and obscured, in part, by the ease with which they can be linguistically coded. This, in turn, may be partially related to the amount of time an individual has to generate linguistic codes for describing them. Thus, one possibility for the symmetric RTs with the nonverbal WS in the present study is that the faces were processed by both hemispheres.

A second possibility for these symmetric findings is that the right hemisphere is more intrinsically involved in the mediation of bi-hemispheric activation (Heilman & Watson, 1977a, 1977b). According to Heilman and Watson, each hemisphere has its own independent activational system, consisting of cortico-limbic-reticular feedback loops, similar to those described by Sokolov (1963). Stimulus receptivity is mediated primarily by cortical systems. With stimulus input, cortical systems that are particularly adept in processing these stimuli are activated. Because of hemispheric differences in mediating verbal and nonverbal materials, it is reasoned that the hemispheric activational systems are

material dependent. Namely, verbal stimuli selectively activate the left hemisphere and nonverbal stimuli selectively activate the right hemisphere.

Beyond these material dependent activational systems, Heilman proposes that the right hemisphere can activate the left hemisphere via interhemispheric communication (Heilman & Van Den Abell, 1978). However, the extent to which the left hemisphere can activate the right hemisphere is considerably less. Essentially, a one-way street phenomenon is proposed in which the right hemisphere activates the left hemisphere more than the left hemisphere activates the right hemisphere, i.e., asymmetric interhemispheric activation.

What type of predictions would be generated from such a one-way street phenomenon regarding the occurrence of perceptual asymmetries for verbal and nonverbal stimuli? For one, it should be more difficult to elicit left-sided advantages for "right hemisphere" tasks than right-sided advantages for "left hemisphere" tasks. In laterality experiments using nonverbal tasks, the presentation of visuospatial stimuli should theoretically activate the right hemisphere. The right hemisphere, in turn, activates the left hemisphere via interhemispheric pathways. Thus, with nonverbal processing, the particular descriptive systems of both hemispheres are activated and called into action. Perceptual asymmetries should, consequently, be difficult to elicit for nonverbal/visuospatial materials.

In laterality experiments using linguistic tasks, the presentation of verbal stimuli should theoretically activate the left hemisphere. Since, however, interhemispheric transfer of activation is less robust going from the left to the right hemisphere (than vice versa), the right

hemisphere should be less activated. Thus, during verbal processing, the descriptive systems of the left hemisphere are activated and called into action. Right-sided asymmetries for verbal materials should be easily obtained.

Experimental support for these predictions is reflected in findings from the laterality literature. Laterality effects for nonverbal materials with normal dextral adults, using either DL or VHF procedures, are generally smaller than effects with verbal materials and less consistently obtained. This is illustrated in a review article by White (1973) of 41 experiments which used unilateral tachistoscopic presentation of either verbal or nonverbal stimuli. In the 16 studies in which verbal stimuli were used, 12 reported a RVF superiority and four reported no VHF asymmetries. In contrast, there was little consistency among those studies employing nonverbal stimuli: 15 of 25 studies reported no hemispheric/VHF differences in recognizing nonverbal stimuli; three reported a RVF superiority; and seven reported a LVF superiority. These data, although compatible with Heilman's proposal, are equally consistent with the notion that nonverbal stimuli are processed bilaterally.

The most direct support for the hypothesis of asymmetric interhemispheric activation, however, is drawn from a manual RT study in which neutral WS were presented to the left or the right VHF (Heilman & Van Den Abell, 1978). Responses were measured to a centrally presented neutral stimulus. Warning stimuli directed to the right hemisphere (i.e., in LVF) reduced RTs of the right hand more than WS in the RVF (i.e., left hemisphere) reduced RTs of the left hand. While these initial findings are compatible with the hypothesis of asymmetric interhemispheric activation, more extensive investigations of this proposal are needed.

Thus, two explanations have been proffered to account for the lack of RT asymmetries with the nonverbal WS. According to one, the nonverbal WS were processed by and activated both hemispheres. The second concerns the asymmetric transfer of interhemispheric activation by the right hemisphere. It should be noted that the interhemispheric activation hypothesis is not only compatible with the notion of bilateral coding, but might represent a mechanism via which bilateral coding of nonverbal stimuli is facilitated.

A second major focus of the present study was to determine the extent to which asymmetric activation is temporally related to the WS. Since RT asymmetries were found with the "go" WS, this suggests that asymmetric activation persists for at least 500-1500 ms (i.e., the interval between the WS and the RT stimulus). A comparable pattern of RT asymmetries was found with the unwarned embedded trials: Right hand RTs tended to be faster than left hand RTs when the unwarned trials were embedded among the verbally warned trials (Hypothesis I); and right hand RTs tended to be faster when the unwarned trials were embedded among the verbal than nonverbally warned trials (Hypothesis III). These RT asymmetries with the embedded unwarned trials suggest that asymmetric activation tends to persist up to 15-20 sec (i.e., the intertrial interval). However, this phenomenon is not stable at this point in time, since the asymmetries with the unwarned trials bordered on, but never quite reached significance.

Taken together, the findings from the "go" and "tonic" trials indicate that asymmetric activation is most robust immediately following the WS and declines 15-20 sec later. Since only two points in time were sampled in this study, it remains unclear at what point asymmetric

activation initially began to decline, whether this decline can be characterized as a decreasing linear function, or at what point activation is no longer asymmetric. In order to determine the "recovery time" of asymmetric activation, the intervals between the WS and the RT stimulus could be systematically varied, i.e., 500 ms, 2 sec, 4 sec, etc.

Following the end of the session (i.e., Post-trials), the predicted RT asymmetries had completely attenuated. Instead, a differential vigilance effect was found on the Post-session trials. Regardless of the hand used, RTs following the verbal sessions were slower than the Pre-session RTs. There was no such increase in RT over time with the nonverbal intervening sessions. Furthermore, the Post-nonverbal RTs were significantly faster than the Post-verbal RTs.

These findings are suggestive of a differential vigilance effect, which appears to be related to the verbal-nonverbal nature of the intervening task. In the present context, vigilance can be viewed as sustained performance (i.e., activation-attention-intention) over time. There are several factors that might contribute to the findings that RTs following the nonverbal task were faster than those following the verbal task.

First, the intervening verbal task may have been less complex, more boring, etc., thereby inducing less activation than the nonverbal task. If this had been the case, however, one would have expected RTs during the verbal session to have been slower than RTs during the nonverbal session, especially as the session proceeded (i.e., a significant main effect for Type WS or a Type WS X Block interaction). This was not found.

Secondly, the face WS may have involved bilateral hemispheric processing. With participation of both hemispheres, there may have been "shared vigilance" in stimulus processing, resulting in more sustained efficiency following the nonverbal task. In this context, work by Dimond and Beaumont (1971) has suggested that task performance is greatly enhanced when both hemispheres "share the load" of stimulus processing.

Third, the proposal of asymmetric interhemispheric activation (Heilman & Van Den Abell, 1978) is also compatible with findings of faster RTs following the nonverbal task. During performance of the verbal task, primarily the left hemisphere would be activated. However, during performance of the nonverbal task, both hemispheres would be activated consequent to asymmetric interhemispheric activation by the right hemisphere. With bi-hemispheric activation, there may again have been "shared vigilance" in stimulus processing, resulting in more sustained efficiency following the nonverbal task.

All in all, the findings of the present study suggest that verbal and nonverbal materials activate the hemispheres and affect behavior in different ways. This activation appears to be temporally related to the WS, has begun to diminish 15-20 sec following the WS, and is completely attenuated following the completion of the task. Furthermore, a response-linked decisional process appears to be critical for inducing asymmetric activation. The symmetric findings with the nonverbal WS do not lend themselves to differentiate between bilateral hemispheric coding versus asymmetric interhemispheric activation by the right hemisphere. The latter can best be distinguished by using neutral stimuli that are not differentially mediated by one hemisphere or the other.

For the most part, the discussion has primarily addressed those predictions that were not supported by the model of material specific hemispheric activation. While several alternative post hoc hypotheses were advanced to account for these negative findings, this in no way exhausts the range of possibilities that may, in fact, exist in the real world. In any scientific inquiry where models of behavior are only partially confirmed, the traditional *modus operandi* is to evaluate critically one's experimental methodology as well as the integrity of the model *per se*. Either the premises on which it is based and/or the predictions generated from them may be faulty or illogical.

In the present study, the hypothesis under consideration states that verbal and nonverbal stimuli differentially activate and prepare the hemispheres for action. Underlying this hypothesis are two implicit assumptions: (a) verbal and nonverbal materials are differentially processed by the two hemispheres; and (b) each hemisphere has its own independent activational system, consisting of reticulo-limbic-cortical feedback loops, as described by Heilman and Watson (1977a, 1977b) and Sokolov (1963). Another component of this activational system might involve basal ganglia-frontal systems for mediating intention.

From these two assumptions, it can be deduced that each hemisphere has its own material specific arousal/activational system. The major prediction generated by this model is that verbal and nonverbal stimuli should asymmetrically activate the hemispheres. In particular, the present study attempted to operationalize a test of this hypothesis by varying the verbal and nonverbal nature of WS in a RT task.

The fact, however, that the findings only partially confirmed the hypothesis leads one to more carefully examine the premises underlying

the model. With regards to the first premise, there is robust support from both clinical and experimental research for the differential mediation of verbal and nonverbal materials (See Tables 1-5).

The second premise, however, is weaker in that it has not been extensively addressed on either a neurophysiological or behavioral level. Behavioral support for this premise is indirectly based on a small, although growing body of research suggesting that there are hemispheric differences in attention. Dimond and Beaumont (1973), based on findings from a series of signal detection studies, proposed that each hemisphere acts as a "watchkeeper" in its own right. Using a vigilance paradigm in which signals were directed to either the right or left hemispheres, these authors found that the accuracy of signal detection by the two hemispheres was markedly different. Accuracy of left hemisphere performance showed a dramatic decline over time. In contrast, signals detected by the right hemisphere showed no such decrement in performance.

Clinical studies using unilateral brain lesioned patients or individuals whose corpus callosums have been sectioned have also supported the premise of hemispheric differences in activation (DeRenzi & Faglioni, 1965; Dimond, 1977; Heilman, Schwartz, & Watson, 1978; Howes & Boller, 1975; Watson, Andriola, & Heilman, 1977). Reaction time studies using unilaterally brain lesioned patients have demonstrated that the RTs of individuals with right hemisphere damage are consistently slower than those with left hemisphere damage (DeRenzi & Faglioni, 1965; Howes & Boller, 1975). Similarly, bilateral GSR hyporesponsivity and bilateral EEG slowing have been reported following right, but not left unilateral lesions (Heilman, Schwartz, & Watson, 1978; Watson, Andriola, & Heilman, 1977).

Thus, there is some experimental support for both initial premises, with the first being more widely documented than the second. In order to account for the disparate findings of the present study, if these two premises are not discarded, one must make modifications in the model. One revision might include the incorporation of the notion of bi-hemispheric coding of nonverbal stimuli. The first premise might be modified, for example, to state that verbal and nonverbal stimuli are differentially mediated by the two hemispheres: verbal stimuli require left hemisphere processing and nonverbal stimuli require bilateral processing.

Alternatively, the second premise might be revised to state that the activational system of the left hemisphere is independent, whereas that of the right hemisphere is more diffuse and nonspecific. Another revision might include the addition of a third premise, stating that the right hemisphere is more critically involved in the mediation of bi-hemispheric activation. Namely, the right hemisphere can activate the left hemisphere more than the left hemisphere can activate the right hemisphere. Each revision, of course, must be put to critical experimental test.

The notion that the right hemisphere is more critical for attention-activation is extremely tentative. Even more tentative is Heilman's proposal that the two hemispheres asymmetrically activate each other, although an initial experimental test has been compatible with this hypothesis (Heilman & Van Den Abell, 1978).

Based on this hypothesis, however, there are several interesting predictions that can be made regarding the performance of unilateral brain lesioned patients on verbal and nonverbal laterality tasks. With verbal tasks, one would make the paradoxical prediction that patients

with lesions to either hemisphere should be impaired. Unilateral left hemisphere lesions should result in performance decrements because of compromise to cortical areas that are specifically involved in linguistic processing. Likewise, unilateral right-sided lesions should also result in performance decrements. In this case, impaired performance would be consequent to the inactivation of the left hemisphere by the lesioned right hemisphere. One would expect, therefore, that the types of errors made by each patient group to be qualitatively different. Patients with right hemisphere lesions would be slower, hypoactive, less attentive, etc., and make errors on that basis. Patients with left hemisphere lesions would make errors on a linguistic basis.

On nonverbal tasks, patients with right hemisphere lesions should be dramatically compromised. Areas equipped for processing visuospatial stimuli are damaged. Furthermore, the right hemisphere, because of its lesion, is less able to activate the left hemisphere. In contrast, patients with left hemisphere lesions should remain relatively intact for processing nonverbal stimuli.

A test of these predictions can be made from a review by White (1973) of 25 laterality experiments using unilaterally brain injured patients. Of the 15 studies using nonverbal stimuli, 13 found greater impairment following right hemisphere lesions, one found greater impairment following left hemisphere lesions, and one found no differences between the lesion groups. Of the 10 studies using verbal stimuli, six studies found no differences between right and left hemisphere groups, two studies reported greater impairment among the left hemisphere group, and two studies reported greater impairment among the right hemisphere group. These findings are compatible with the interhemispheric activation hypothesis.

As stated in the introduction, one general purpose of the present study was to determine whether attentional mechanisms might contribute to and partially account for perceptual asymmetries. Traditionally, perceptual asymmetries have been thought to derive from a fixed pathway-transmission model in which verbal and nonverbal stimuli are better perceived when presented to the ear/VHF which has most direct access to the target hemisphere. The particular paradigm employed in the present study enables one to rule out interpretations of the data according to a pathway-transmission model, since responses were measured to a neutral stimulus which is theoretically processed equally well by both hemispheres.

The elimination of the direct access hypothesis as an explanation of the present findings, however, does not imply that it is an unimportant construct. Rather, its elimination allows one to consider additional mechanisms which might also contribute to perceptual asymmetries. If, for example, no RT asymmetries had been obtained in the present study, the material specific hemispheric activation hypothesis could be tentatively discarded. It is of interest, however, that whereas a direct access model cannot account for findings such as those presented here, the activational hypothesis can be used, in part, to interpret these findings as well as those from traditional laterality paradigms.

A final consideration concerns the implications of these findings for Kinsbourne's (1970a, 1975) cognitive set hypothesis of perceptual asymmetries. According to his model, robust between-hand RT asymmetries would be predicted for the unwarned trials ("Tonic" and "Post-session"). The WS should theoretically induce verbal/nonverbal cognitive sets which

would then asymmetrically affect the neutral trials. This was not found. This suggests that either the cognitive set hypothesis of perceptual asymmetries is incorrect or that the mechanism via which a cognitive set is mediated is not attentionally based in the manner described by Kinsbourne.

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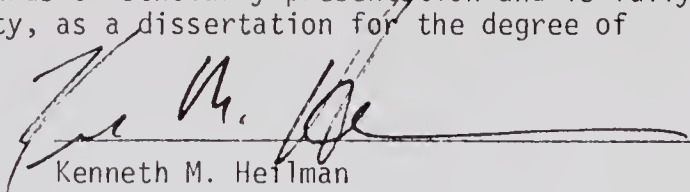
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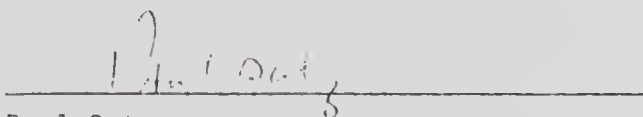
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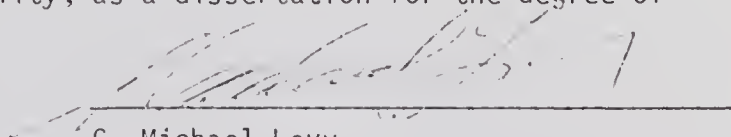
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Chairman  
Professor of Clinical Psychology

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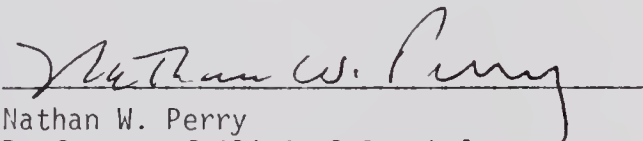
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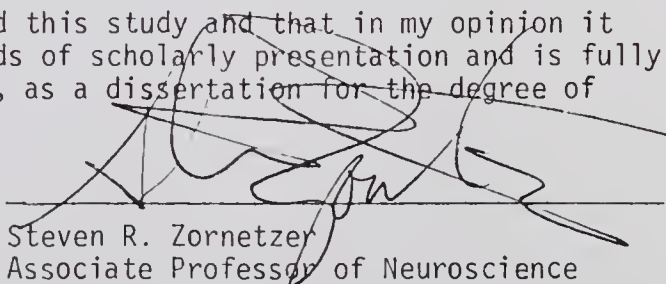
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This dissertation was submitted to the Graduate Faculty of the Department of Psychology in the College of Liberal Arts and Sciences and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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